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STUDIES ON LIQUID FILMS.*

BY

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Fullerian Professor of Chemistry, Royal Institution; Honorary Member of the Institute; Franklin Medalist, 1919.

SOME problems presented by liquid films were discussed in the Discourse of 1917[1] and in a contribution to this Journal.[2] These studies have been continued and further developed in the restricted time left for research after meeting the demands of the Government departments; but such conditions imply a certain amount of discontinuity which cannot but leave its mark on the inquiry.

BUBBLES FOUR FEET IN DIAMETER.

In order to increase the size of bubbles above those described a year ago (46 cm. in diameter), advantage was taken of a cool cement-lined cellar (some 600 cubic feet capacity) which was so fitted that the nozzle and blowing tube were passed through the door and controlled from outside. All apertures and cracks were filled with glycerined cotton wool. The atmosphere of the cellar was several times cleaned and renewed by pumping in purified air, but no permanent purity could be maintained. In less than two

* Communicated by the author. Lecture delivered before the Royal Institution, January 18, 1918, and later to appear in its Proceedings.

[1] "Soap Bubbles of Long Duration," *Proc. Royal Institution*, vol. xxii, 179.

[2] "Soap Bubbles of Long Duration," vol. 188, p. 713.

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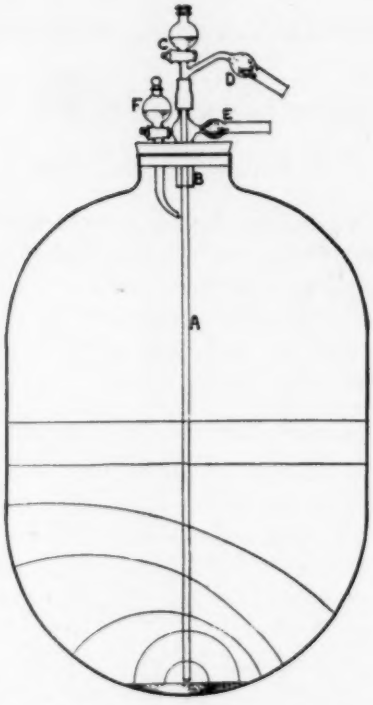
days the Tyndall cone would reappear. Large sheets and trays smeared with glycerin were of no assistance in reducing the mist, so that although bubbles up to four feet in diameter were obtained, they did not last above a few hours.

PLANE BLACK FILMS 2500 SQ. CM. IN AREA.

At the Discourse given a year ago a stoppered vessel was shown which contained a plane black film 19 cm. in diameter; the film was then one week old, and has remained unchanged to this date.

FIG. 1.

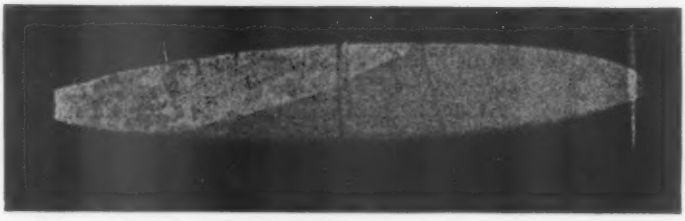


For the purpose of extending the study to larger films, the cylindrical globes that were used last year for the examination of 40 cm. bubbles were employed. Plane films 56½ cm., or nearly two feet in diameter, were thereby obtained which lasted for 40 days, and even more, after becoming entirely black. Fig. 1 shows a globe fitted for this purpose. About half a litre of soap solution having been run in, and the end of the tube A dipped into it, a

bubble, blown by pure air, was started and gradually expanded, as shown by the various stages of the diagram, until it became a plane horizontal film about the middle of the vessel. Some idea of the appearance of the film in the globe can be gathered from Fig. 2, reproduced from a photograph taken with a white screen placed behind and a little above the film, thus reflecting diffused light.

The globe and its fittings must be scrupulously clean, and the interior free from all traces of floating matter when tested by the Tyndall cone of light. By careful manipulation the soap solution was made to flow all over the inside, while the tube A was also

FIG. 2.



wetted by a stream of soap solution from a dropping funnel F fitting tightly in the rubber cork used to close the neck of the globe. The tube A can slide freely up and down in the support tube B, to which was sealed the bulbed outlet E. The upper part of A could, on occasion, be fitted with a dropping funnel C, sealed to the vertical portion, while still connected to the bulbed nozzle D, by which pure air was admitted. The bulbs D, E were loosely packed with cotton wool moistened with glycerin. C was only used when subsequent additions had to be made to the soap solution in the globe.

After the plane film was obtained in the right position midway in the globe, A was raised until its lower end was a few inches below the film. The nozzles D and E were open, but were provided with soda-lime guard tubes, so that the spaces above and below the film were equally open to the atmosphere, though guarded from contamination. This ensured that the fluctuations of the atmosphere were equalized throughout both portions of the relatively large space of the globe; otherwise the film was not likely to last long because of the vertical displacements that would occur. In one case a barometric alteration of 1 cm. in 20 hours caused the film to move through 5 mm. After the globe has

drained for a day or two, there is not enough liquid left on the walls to keep the film sufficiently lubricated to allow of such oscillations. The only liquid available is in the tiny channel—the Gibbs layer—round the periphery of the film. This channel is roughly triangular in section, with the base of the triangle on the glass walls, and the concave sides converging to the film which extends out beyond the apex of the triangle. In a very well-drained film the base of this triangle may not be more than 0.1 mm., so that the sectional area of the channel is about $\frac{1}{20,000}$th of a sq. cm. The total liquid available round such a film 56 cm. in diameter is, therefore only about 1 cgm. It is obvious that long before such complete drainage as this is reached any movement of the film occurring over a relatively dry surface will quickly exhaust the liquid in the channel, and the film will be ruptured. However, when the proper precautions were taken, the displacements due to atmospheric variations did not amount to more than 1 or 2 mm. for weeks together.

Until they become completely black very striking color effects can be seen in these large horizontal films. They have of course only a small gradient of thickness, so that the bands of color are drawn out into large areas. During this period convection in the films is most easily seen, because of the brilliant contrasts afforded by the moving portions. Should there be much fluctuation of temperature, the complete development to the black state may be arrested, the last part of the colored area being kept in intermittent circulation for several days. Superfluous liquid draining down outside the central tube will produce a similar result by becoming spread out on the black film surface as a colored clot round the tube. When this clot grows sufficiently it will draw off slowly, and pass down the radius of greatest inclination of the film. It formed on one occasion an ellipse (1 cm. by 1½ cm.), which took 35 seconds to traverse the last one-fourth of its path. On approaching the periphery where the film curves up slightly into contact with the glass, the clot flattened out and curled into the most intricate convolutions, finally sweeping round close to the edge, a writhing mass of colored streaks, many of which became roving stars on the black film. The whole colored area was finally drawn into the Gibbs ring, from which frequent escapes of small drops of liquid took place.

A favorable condition for longevity is a quiet temperature

rather below 10° C. Sudden alterations of 3° or 4° C. are most likely to burst the films by provoking too rapid convection therein, as is evidenced by very rapidly moving streams of silvery stars drawn from the Gibbs ring.

The vibrations which occurred during the operation of the air compressors in the laboratory did not affect the final stability of

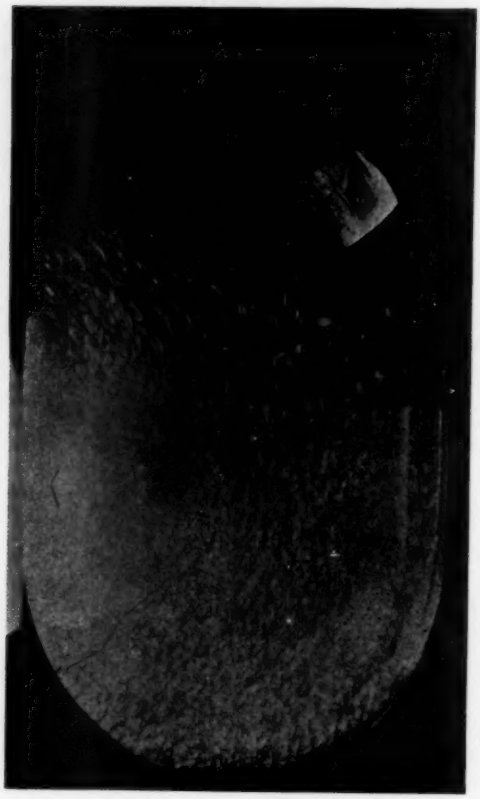
FIG. 3*a*.

the black films. A stationary circular wave was produced having an amplitude of over 1 mm. vertically all round a circle midway between the central tube and walls of the globe. This motion continued the whole time the machines were working, but the films always survived.

Instead of having one large plane black film, a mesh-work of black films can be obtained completely filling the globe. To pro-

duce this, the lower end of the blowing tube A (Fig. 1) is inserted slightly below the surface of the soap solution. The air current being regulated suitably to the diameter of the tube A, a steady succession of uniform bubbles is produced. The surface of the glass having previously been well moistened, the issuing bubbles

FIG. 3*b*.

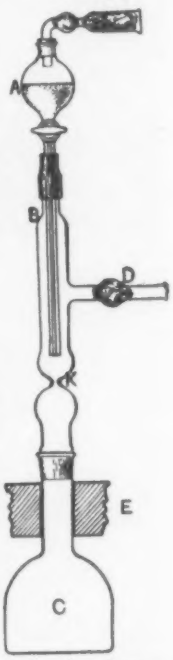


consequently encounter little resistance, and develop rapidly, linking up into a glittering lustrous froth which increases until the globe is full. Excess liquid drains away very rapidly, the black stage being reached in about an hour. The beauty of the mass can be seen properly only when a beam of light is flashed upon it in continually changing directions, the different inclinations of the

internal plane films giving rise to a continuous series of brilliant scintillations (Fig. 3*a*). The same appearance is perhaps still more remarkable when the mesh-work is lit up by diffused light from rays thrown across the observer's line of vision (Fig. 3*b*). A black background is used in both cases.

The internal walls of the various cells being plane polygons, the pressure of the air in these cells is the same for all, and is regulated according to the curvature of the cell-walls on the outer boundary. As transference of the enmeshed air from the mass can take place only through the curved boundaries of the outer layer of bubbles, contraction of the mass from this cause is relatively slow. In one case it required a fortnight for the initial volume to be reduced to one-half.

FIG. 4.



To obtain the best result the blowing tube A should be withdrawn when the mesh-work has been completed, as it exerts some protecting power over the bubbles that closely surround it, thus causing an annular depression farther out, and tending to destroy the mass.

COLUMNS AND CHAINS OF BUBBLES.

For the purpose of studying bubble clusters and film complexes, instead of single bubbles and plane films, an arrangement of the nozzle was employed, by which it was possible to get a succession of bubbles of any required volume, linked together, in one operation. The apparatus employed is shown in Fig. 4. A is a stoppered reservoir of soap solution from which a capillary tube passes down the air-supply tube D, B, to about 1 cm. above a constriction K. After passing K the lower end of the air-supply tube is, for convenience, fitted by a ground joint to an enlarged nozzle C, securely held in position by the rubber cork E. The stopper A being opened at regulated intervals of time a series of drops falls on the constriction K, which are immediately blown into films by the constant air current entering through the bulb D (protected as before by lightly packed glycerined cotton wool). Hence a series of bubbles is produced at the nozzle C, which may have equal or

different volumes as desired, and may be further controlled so as to present themselves either as a vertical column or as a cluster.

The shape of the cluster obtained depends on the dimensions

FIG. 5.

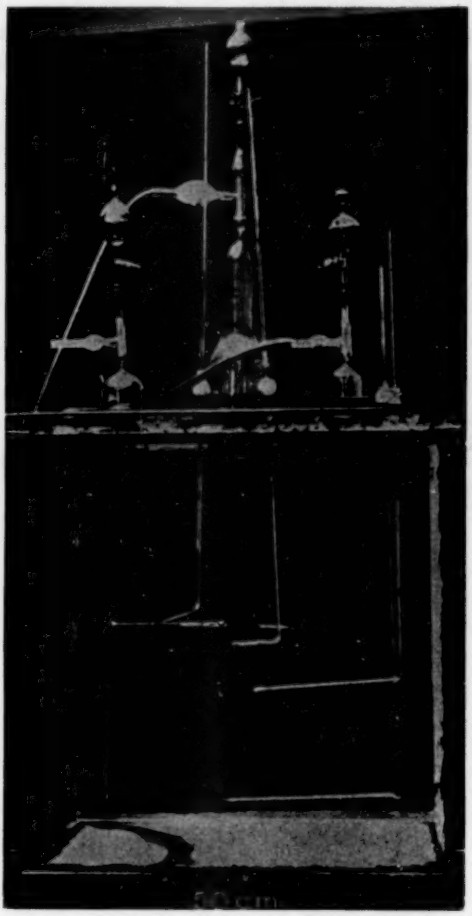
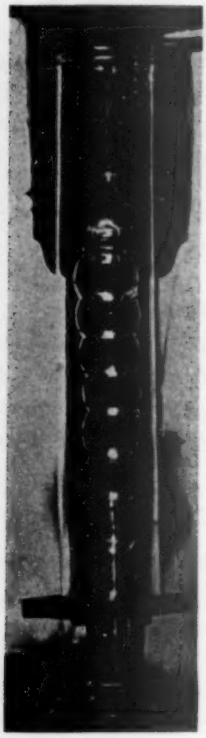


FIG. 6.



of the nozzle, the speed of the air current, and the relation between the mass of the drop and the size of the constriction. If the drop be too large or the air current too slow, extra films result from the accumulation of superfluous liquid; the same thing happens with an enlongated constriction. On the other hand, too rapid a current

may simply spray the liquid over the interior of the nozzle. The cleanest working is obtained from a short neck blown out above and below in a spherical shape as shown in the figure at K.

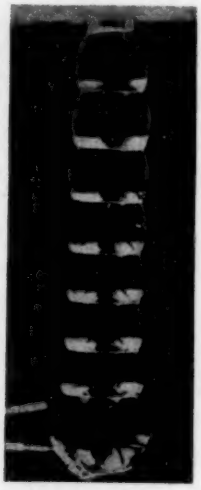
A succession of equal bubbles may either form a regular cluster on the mouth of the nozzle, or a vertical chain or column of spherical segments united by plane circular films. A cluster will usually be formed when the bubbles are less in diameter than the nozzle, and a chain or column when the bubbles are larger. For the manipulation of these complexes an air-tight, cubical, plate-glass chamber was made (Fig. 5.), on a frame of aluminum alloy (edge, 50 cm.). The glass plate for the top was 1 cm. thick; holes were cut in it for the rubber corks that held the nozzles and supported the movable glass rods which carried the different small pieces of apparatus used to catch and control the chains while being formed.

For the manipulation of the longer columns the glass cylinder shown in Fig. 6 was used. It was 3 feet long and 6 inches in diameter; its ends made air-tight joints with two plates, the upper of which held the blowing nozzle, while the lower held a support ring. Suitable exit stopcock and soda-lime guard tube were also fitted. The support ring was sealed to the top of a vertical rod that could slide up and down in an air-tight joint in the bottom plate. The cylinder was fixed on a shelf in the middle of a massive wooden stand, and a hole was cut in the shelf to allow free movement to the sliding rod. When a to-and-fro motion was given to the support rod, the flexibility of the column was readily seen; transverse waves appeared to pass up the whole length, each segment moving on the one adjacent as if attached by a very free universal joint. By drawing the rod down a considerable extension could be obtained; contrariwise by raising it a bulging or spiral formation would result. If this be carried further and the surface be sufficiently moist, the column will sag out into contact with the glass walls and form a chain of oval segments. In a wider vessel, however, the segments can in this way be linked up successively to form regular clusters.

A beautiful exhibition of multiple scintillating colored reflections is obtained when a beam from an arc lamp below is directed up through the column while the support rod is moved. An even more complete illumination is secured by using a white lined hood above, in which is hidden a 200-watt lamp, with two white

wings of stiff card fixed one on each side of the central black stand. These side screens alone are sufficient for this purpose if the whole apparatus stands in a good light. A striking contrast is obtained when the column is drained to blackness and illuminated by a beam from below, if an occasional drop of soap solution is allowed to trickle down through the nozzle. Before this is done very little is seen except the bright point reflections from the curved surfaces; but, as the falling drops arrive in rapid succession at the planes between the adjacent segments, the thin circular channels flash

FIG. 7.



up into sparkling silvery light from the internal reflections of the accumulated liquid. Fig. 7 gives some idea of the appearance.

The following particulars show how some of the results were obtained:

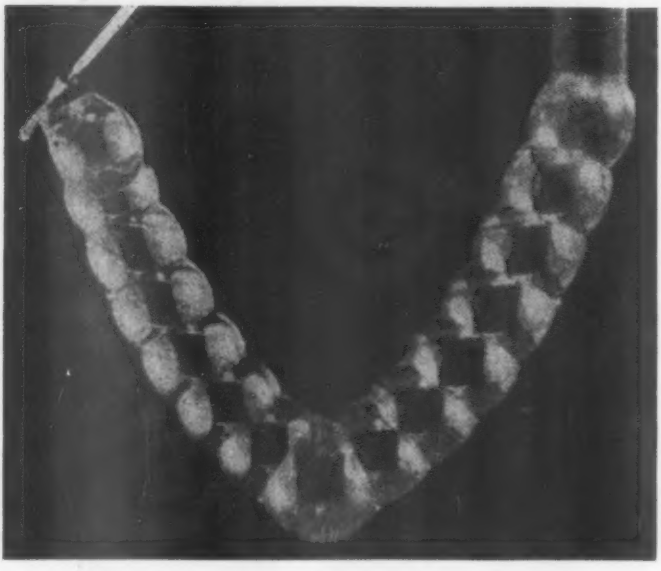
(*a*) Nozzle, 3 cm. diameter; constriction, 1.15 mm. bore; drop, 18 mgms.; air current approximately 500 c.c. a minute; drop interval, 5 seconds; giving a volume of 42 c.c. for each segment. While they were being blown the free end was caught on one of the movable glass rings already mentioned, by means of which fifteen bubbles were steadily drawn out into a flexible catenary with its ends 13 cm. apart (Fig. 8).

(*b*) Nozzle, 3.4 cm. diameter; air current, 565 c.c. per minute; drop interval, 7½ seconds; giving a volume of about 70 c.c. for

each segment. A column of eight of these bubbles reached from the rim of the nozzle to the wet floor of the cube, where contact was made. The same nozzle could give a chain of nine bubbles of three times this volume.

(*c*) Same nozzle; air current, 305 c.c. per minute; drop interval, 9½ seconds; giving a volume of about 48 c.c. for each segment. A column of ten of these bubbles was held on a fairly

FIG. 8.



straight axis inclined at about 50° to the horizontal after they were drained free of excess liquid.

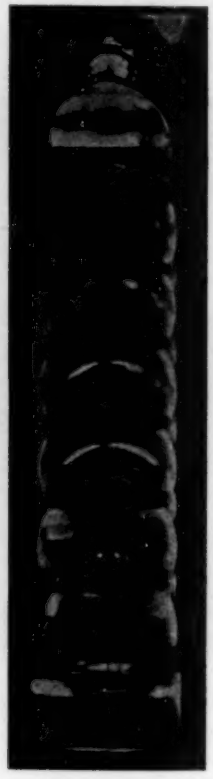
Some of these chains are liable to break with excess liquid (Fig. 8). This can be largely obviated by using a percentage of hydrogen in the air current, provided an atmosphere of pure air is maintained in the glass cube. The buoyancy of the bubbles is thereby increased for a time sufficient to allow the column to be manipulated. When the chain has once been secured any further accumulation of liquid must be continually removed. For this purpose a fluted glass rod some 2 mm. thick and 3 or 4 cm. long was very effective. (It was made by drawing out a bundle of seven small glass rods in the blow-pipe, and was utilized by attach-

ment to one of the movable bent glass rods passing through the top of the cubical box.)

When very large bubble segments are required it is safer to interrupt the air current between two adjacent segments, while a

FIG. 9.

FIG. 10.



few extra drops of liquid are run in to remoisten the glass surfaces. In this way bubbles of over 1 litre were obtained on a nozzle 5 cm. in diameter, with a constriction of 1 mm. bore, and a 25 mgm. drop. Four of these linked together and forming a chain inclined at about 45° to the vertical were photographed on a Lumière autochrome plate, which, in addition to the colored contours, showed clearly the brilliant bands on the plane films between the equal segments. To obtain these photographs the cubical glass vessel was

placed in full sunlight. The top and two opposite sides were covered with thin tissue paper to give uniform diffuse illumination. Black paper formed the background, while the front was left clear for exposure to the camera. On a quarter-plate an exposure of 40 to 60 seconds was necessary. A 9 by 7 inch Ross portrait lens

FIG. 11.

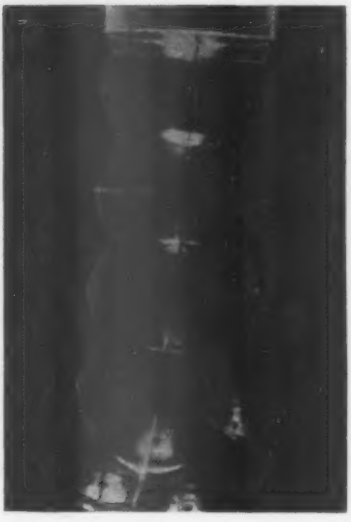
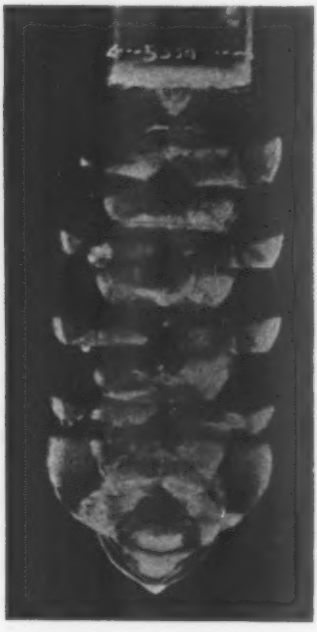


FIG. 12.



was employed at F. 11. Color photographs of several of the columns have been obtained in this way.

MULTIPLE COLUMNS.

Regular formations of greater complexity were obtained when the bubble elements were reduced in size so that their diameters were less than that of the nozzle. Thus, for example, two columns which coalesced into one are shown in two perpendicular views in Figs. 9 and 10 (see also Fig. 24). The horizontal plane films between the successive elements of both columns were linked by a "staircase" of films, inclined right and left at 120° to the horizontal films; every bubble thus fitted into two bubbles of the

adjacent half column, the horizontal junction films being segments of circles, while the inclined films took the form of rectangles with their short sides slightly convex. The data for this formation were: Nozzle, 5 cm. diameter; air current, 130 c.c. per minute, with an interval of 15 seconds between successive drops. Each element of the column thus had a volume of 32½ c.c. Three columns will also coalesce from top to bottom, twining round each other like the spiral strands of a rope. The plane films linking the bubble segments are then truncated sectors of circles.

A complex of four interpenetrating vertical columns is shown in Figs. 11 and 12. This may be considered as built up by a succession of horizontal pairs of bubbles, each pair being at right angles to the adjacent pairs above and below. The symmetrical pairs of horizontal plane films which link them are circular quadrants with their points in contact, and of course are alternately at right angles.

FIG. 13.

Between each member of the alternate horizontal pairs of bubbles there are vertical films which are diamond-shaped, and joined at their apices with their planes alternately at right angles along the axis of the cluster. The resulting appearance is very regular. One example of this formation was produced by a nozzle of 5 cm. diameter, with an air current of 400 c.c. a minute, and an interval of 4 to 5 seconds between the drops.

A still more complex but perfectly regular quadruple column has the simple string of diamond-shaped films replaced by alternate hexagons and squares of which only the hexagons are vertical. An isometric view of this part of the arrangement is shown in Fig. 13. The common edges of adjacent squares and hexagons are horizontal, and alternate squares are equally inclined in opposite directions to the axis of the complex column. The complete configuration is shown in Figs. 14 and 15 (two perpendicular views); the outlines are further displayed in Fig. 16.

Multiple columns of a higher order were obtained by lessening the time-interval between the drops. The excess liquid thus supplied tended to distort the cluster. This was avoided by employing a long nozzle within which the network of bubbles was formed and supported until the excess liquid drained away. The

cluster was then expanded clear of the nozzle, and remained stable and undistorted. As many as seven or more interlaced vertical columns were obtained in this manner. The centre bubbles of the cluster were of course completely enclosed, and hence had no curved surfaces, but formed instead a chain of film-enclosed cells. From the outermost facets of these there radiated a film structure of pyramidal frustums bounded externally by curved bubble films.

FIG. 14.

FIG. 15.

Two forms of these faceted "cells" are shown in Fig. 17; some have the regularity of a well-cut gem, and exhibit great brilliance in a concentrated light. Some forms frequently occurring have (*a*) parallel regular hexagons top and bottom with pentagonal facets; others have (*b*) irregular heptagons at the top and bottom; the facets being then either pentagons alone or alternate hexagons and quadrilaterals, or even all three together. An interesting example occurred when the quadruple column with alternate diamond-shaped planes distributed along the axis (Fig. 11) was disengaged from its nozzle and allowed to fall on the surface of

the soap solution 15 cm. below. The cluster had already drained to complete blackness, and was therefore so light that at first it rebounded several cms., finally floating on the surface for some time, delicately poised like a nautilus. However, it soon coalesced with the liquid surface, forming a half dodecahedron in the centre surrounded by a symmetrical ring of six half bubbles all resting on the liquid, and three whole bubbles superposed regularly above

FIG. 16.

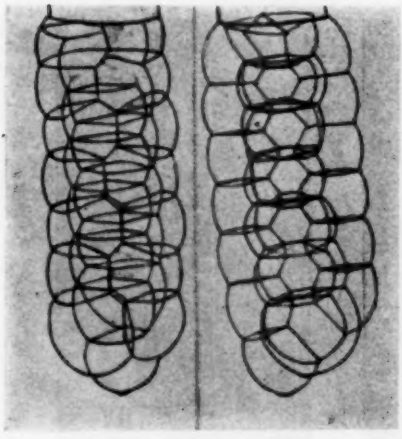
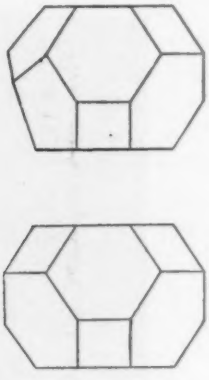


FIG. 17.



these, each of the nine external bubbles springing from one facet of the central "cell." The completed structure, of which this was the half, would thus have consisted of twelve pentagonal pyramidal frustums round a dodecahedron, the bases of the pyramids being the outer curved bubble surfaces. Such a complex was obtained separately, but it is difficult to show the configuration by means of a photograph.

SYMMETRICAL CLUSTERS OF BUBBLES.

Equal-sized bubbles are readily built up into well-defined groups that have many interesting properties. Their spherical contours, interlaced by a network of reflecting films, give them a graceful symmetry. Up to an aggregate of eight the growth is fairly simple. Each successive bubble springs instantaneously into its place with the appearance of being partly absorbed, though of course retaining its volume practically unchanged. Two bubbles

thus coalesce into two spherical segments joined by a circular plane film. When a third bubble is introduced between these two the spherical boundaries are further reduced, and are spaced out between three equally inclined plane films, which are segments of circles in contact round the axis of symmetry.

With four bubbles there are two possible arrangements; the more stable form has the fourth bubble resting symmetrically on the group of three, so that the four segments are equally spaced on the frame of a regular tetrahedron. Six plane films in the shape of circle sectors are thus produced by the four segments coalescing

FIG. 18.

round the centroid of the tetrahedron (Fig. 18*a*). But if the fourth bubble be introduced between any two of the three-group instead of at the junction of all three, then the form shown in Fig. 18*b* is obtained, which has a central plane film shaped like a rectangle with its short sides slightly curved, and two pairs of equally inclined planes springing from its long sides. These five planes constitute a frame linking the four bubble segments together.

In Fig. 19 these frames outlined in wire are shown as they appear (*a*) for the group of three; and (*b*), (*c*) for the two forms

of the group of four; while Fig. 20 (outer set) gives the sections through the groups to show the inclination between the plane films, and the trace of the outer contours.

FIG. 19.

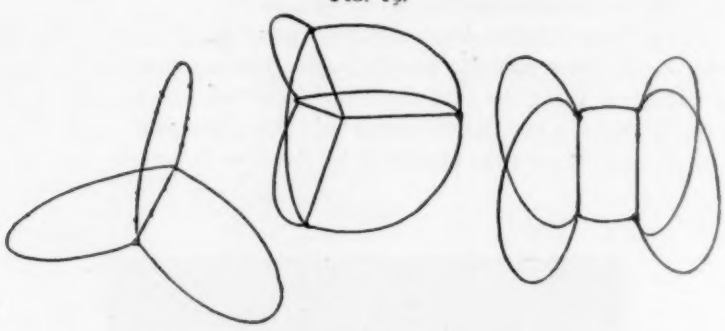
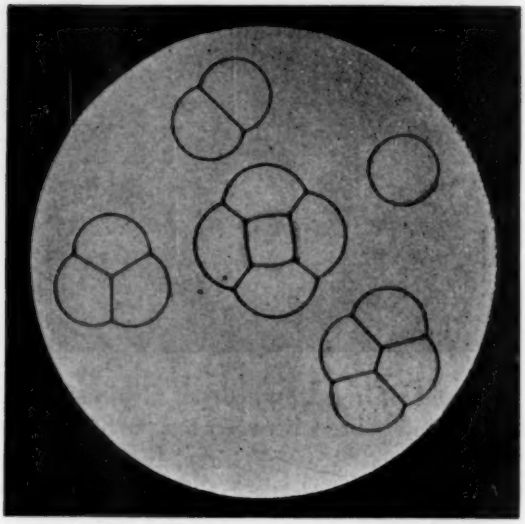


FIG. 20.



Only one arrangement of the five-group has been obtained. It is formed when two additional segments interpenetrate, one at each end of the axis of the three-group, the three upper plane films thus formed, meeting in one point of this axis, and the three lower plane films meeting in another point of the same axis.

The groups of six, seven and eight all have the same type of symmetry—namely, at the centre is a small plane polygon, from

FIG. 21*a*.

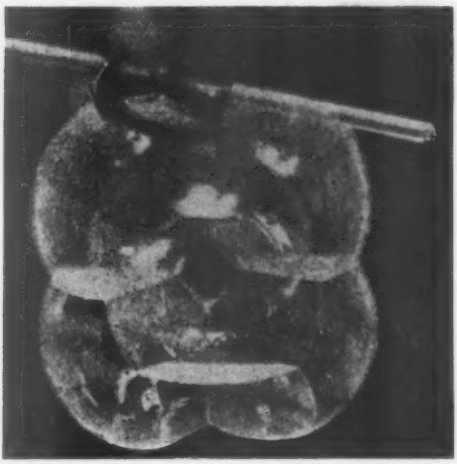
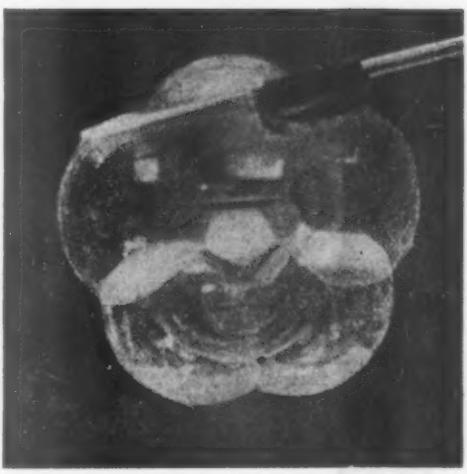


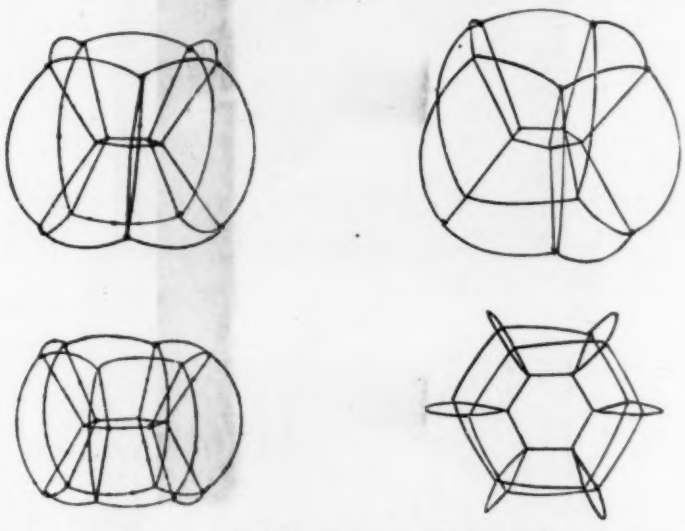
FIG. 21*b*.



the sides of which there radiates a ring of bubble segments, equally spaced, with two others on an axis at right-angles to the central plane. The six-group therefore has a ring of four segments round

a square central plane, the two others being on opposite sides of this central plane. The two interlocked bubble segments thus take the form of two truncated square pyramids in contact with each other on the central square plane, having their bases bulged out on the spherical contour, and the four other segments built in round the faces of the truncated pyramids (Fig. 21*a*). The section of this is shown in the central group of Fig. 20. The groups of seven and eight are similarly formed, except that the square central plane is replaced by a pentagon and hexagon respectively. In all cases

FIG. 22.



the polygon edges are slightly curved. Fig. 21*b* is a photograph of the seven-group with pentagon centre. The wire frames for this group and the eight-group with hexagon centre are shown in Fig. 22, while sections through the two are given in Fig. 23.

These " sections " are in reality photographs of the half groups when formed on a horizontal glass plate (4 inches square). A fountain-pen filler was used to make the equal half bubbles, by simply squeezing the indiarubber bulb quite flat, the nozzle having already been dipped in soap solution, and the glass plate well-moistened with solution. The single and double columns already described may be shown in the same simple manner (Fig. 24). By using the horizontal projection lantern these figures are plainly shown on the screen.

FIG. 23.

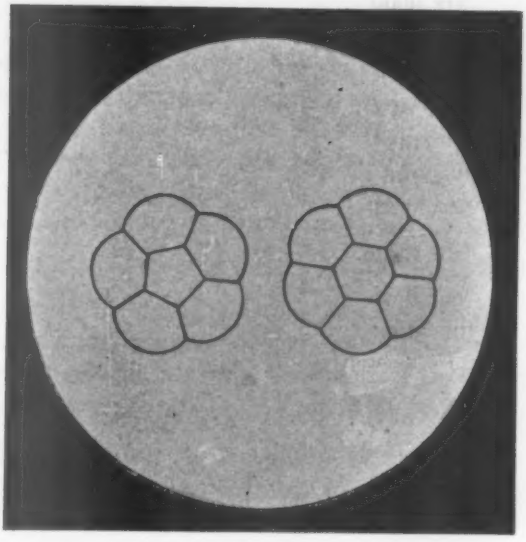
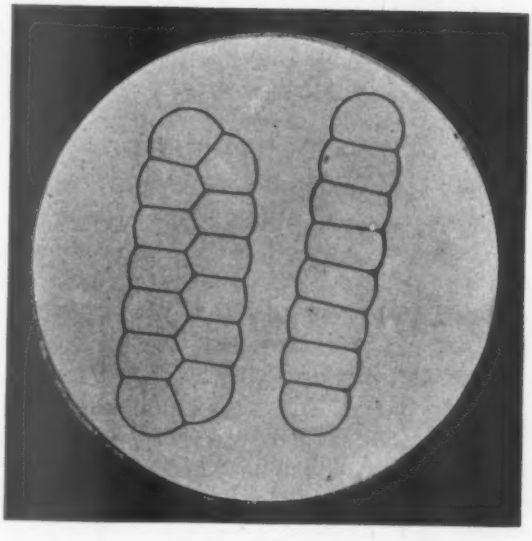


FIG. 24.



The forms taken by these clusters are governed by the conditions for equilibrium of the surface tensions at the intersections of the films. Not more than three films can meet in any one line, and if they are planes they will be equally inclined to one another at angles of 120°, while, if they are curved, then the law of equal inclinations holds between the tangent planes at all points of contact. Taking first the case of two bubbles which have coalesced into two segments united by a circular plane film, the tangent planes at any point of the line of contact of the curved surfaces will be inclined at 120° to each other and to the circular plane. It follows that the radius of the plane central film is $\frac{\sqrt{3}}{2}$ of the radius of the two equal spherical segments, the distance between their centres of curvature being equal to this radius, which is greater than the radius of the original separate bubbles in the ratio of $\sqrt[3]{4}$: 1.5 or 1.0 : 0.9452. Therefore the internal excess pressure (which is inversely as the radius of curvature) is reduced 4.5 per cent. by the coalescence. Measurements made on two bubbles gave under 5 per cent.

Three spherical segments in contact are each approximately five-sevenths of a whole sphere. The internal pressures therefore are now reduced to the proportion of $\sqrt[3]{7} : \sqrt[3]{5}$ or 1 : 0.8933. Now $0.8933 = (0.9452)^2$, so that the process appears to proceed by a geometrical progression, each linkage reducing the internal pressures in an equal proportion.

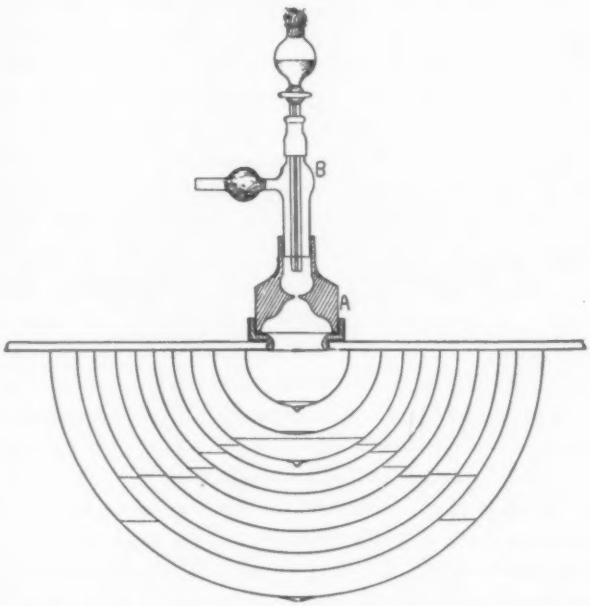
CONCENTRIC HALF BUBBLES.

An interesting application of the method of film formation by regulated drops was made in order to obtain a group of concentric hemispherical bubbles. It was desired to obtain them with a uniform difference of radii of 1 cm. between successive film surfaces. They were blown on the under side of the top glass plate of a smaller cubical vessel (30 cm. length of edge). A special form of nozzle was made with its rim flush with the surface on which the bubbles were to be blown. The part containing the narrow neck was of ebonite, and had a shoulder carefully fitted to the aperture in the glass plate. The dropping funnel and glass blowing tube were fitted tightly into the neck of the ebonite nozzle. Fig. 25 shows the arrangement with a group of ten half bubbles, the horizontal

lines indicating the levels reached by black zones on the fourth day.

In order to determine the time at which each drop had to fall the volumes of the successive bubbles were calculated and their differences tabulated. Having fixed upon a suitable rate of blowing, the intervals between the drops that corresponded to the successive differences in volume were at once obtained. The rate of blowing was 216 c.c. per minute, so that the whole group took about 21 minutes to make, the intervals between the drops

FIG. 25.



decreasing from about 4½ minutes at first to about half a minute at the end. The surfaces of the glass plate and nozzle were first moistened with soap solution.

By the eighth day the black zones occupied 90 to 95 per cent. of the surfaces. Some experiments were made subsequently on the manner of diffusion of hydrogen through the group.

FILM CONTOURS SHOWN BY SHADOW.

When the shadows of these film complexes were thrown on a transparent screen every detail of their structure was clearly shown. For lecture purposes an arc lamp was used to produce

these shadowgraphs, but in the laboratory a beam of parallel rays throwing the shadows on a sheet of tissue paper fixed on the side of the cubical glass chamber (containing the film-cluster), opposite to the source of light, gave means of making accurate measurements both of lines and inclinations of planes, as well as careful tracings for further study. Fig. 16 shows the shadow picture given by the quadruple column shown in Figs. 14 and 15.

WIRE MODELS OF BUBBLE CLUSTERS AND PLATEAU FRAMES.

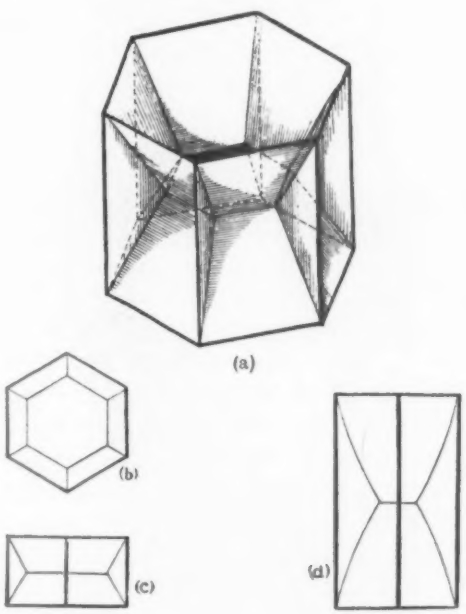
The wire frames already mentioned can be used to build up the corresponding clusters. When they are dipped in soap solution linked films are formed on every plane outlined by the wires, because these are in the same stable relation that exists in the associated bubble group. It is then possible to insert bubble segments into the spaces between the planes and thus build up the actual cluster on a wire frame.

These form an interesting comparison with the well-known Plateau film groups, which were formed on wire frames made in the shape of geometrical solids—cube, tetrahedron, triangular prisms, etc. When such frames were dipped in soap solution linked film planes were obtained in beautiful regular formation, though not necessarily lying in the planes of the solid figure represented in skeleton by the wire, because these planes are not the stable planes of liquid films in contact. The film figures finally obtained were enclosed within the space of the skeleton figure. Thus the films initially obtained on the six faces of the skeleton cube are pulled inward until they meet at an angle of 120° instead of the original right-angle. As a result a small vertical or horizontal square is formed at the centre with a pair of equally inclined truncated triangles radiating from each of its edges to the parallel edges of the cube; this gives eight equal truncated triangles linked by the central square. If a small bubble is included, this is drawn into a cuboid at the centre with the remaining planes as before. So with a tetrahedron, six planes are seen to be drawn inward one from each edge, to the four lines joining the apices to the centroid. This point is therefore common to the six planes which thus divide the space inside the tetrahedron into four equal and similar parts, like the conventional model of the four affinities of a carbon atom. A double tetrahedron has this appearance repeated at each end. Using an octahedron frame, we obtain six kite-shaped

figures, in three perpendicular pairs, linking the three pairs of opposite vertices, and having their obtuse ends fitting alternately at the centre, while the acute ends stretch out to the apices. These six kites are connected to the twelve edges of the frame by twelve triangular planes, making eighteen films altogether.

A hexagonal prism is an interesting case illustrating the impossibility of getting more than three films to meet at one point. A

FIG. 26.

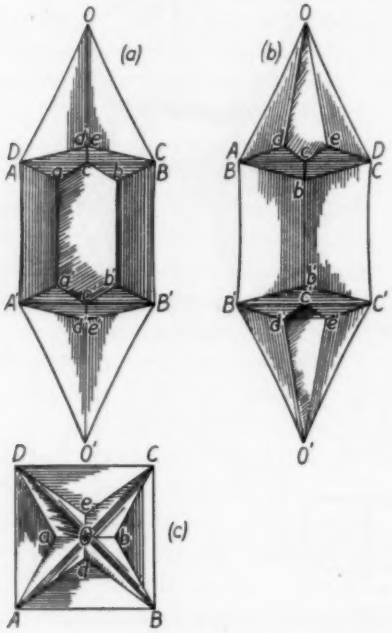


wire prism of indifferent dimensions—say, with its hexagonal edge of the same order of length as its height—will give six triangular vertical films directed from each vertical edge toward the centre, where their apices are linked by a horizontal hexagon (Fig. 26). There are in addition six pairs of truncated triangular films linking top and bottom opposite hexagonal prism edges to the parallel central film hexagon, Fig. 26 (a, b, c). If the prism height is increased and this configuration preserved, then the central hexagon will decrease in dimensions and should vanish when the height of the prism is three times its hexagonal side, all the eighteen films then meeting at the centre. What happens during

the process is shown in Fig. 26 (d): The central hexagon is preserved, the vertical planes are no longer triangles but have sides concaved towards the apex, while the twelve remaining surfaces springing from the top and bottom edges are curved and look like a sort of hexagonal hour-glass—seen in profile (d). The condition governing all these arrangements is the equal inclinations of the tangent planes at the lines of intersection.

One interesting variation of this study was made by employing

FIG. 27.



a frame composed of two thin platinum wire squares, linked by cellulose fibres vertically between the corners to form a cube, and supported by a pyramidal frame formed by four equal fibres from the upper cube corners joined together at the supporting apex. A similar pyramidal frame inverted was also formed below, the four fibres in this case being attached to a small lead weight. The resulting formation when the framework was dipped in soap solution is represented geometrically in the following three views, two elevations (*a*) and (*b*) and a plan (*c*) (Fig. 27).

This is really a combination of the cube and the octahedron patterns (already described) obtained by equally dividing the octahedron horizontally, and adding the separated portions to the top and bottom of the cube. The central square plane of the simple cube is thereby pulled out to an irregular hexagon *a c b b′ c′ a′* by the kite-shaped planes O *d c e*, O′ *d′ c′ e′*, of the divided octahedron, with a consequent rearrangement of all the films at equal inclinations.

The truncated triangular films joining the vertical edges of the cube to the central (hexagon) plane then become very short. In Fig. 27 (*a*) they are shown by A *a a′* A′ and B *b b′* B′, while in Fig. 27 (*b*) the other two are shown by C *b b′* C′, and by D *b b′* D′ behind. All four are shown in profile in Fig. 27 (*c*) by the lines A *a*, D *a*, B *b* and C *b*. The kite-shaped planes from the apices O and O′ of the divided octahedron are Fig. 27 (*b*) O *d c e* and O′ *d′ c′ e′*, which in Fig. 27 (*a*) are only seen in profile—*i.e.*, perpendicular to the central irregular hexagon *a c b b′ c′ a′*.

The edges of the two pyramids (half-octahedrons) being O A, O B, O C, O D, O′ A′, O′ B′, O′ C′, O′ D′, then the triangular films drawn in from four upper edges are in Fig. 27 (*a*) and (*b*) O A *d*, O B *d*, O C *e* and O D *e* behind O C *e*. Similarly for the four lower edges. These triangular films also seen foreshortened in Fig. 27 (*c*) are indicated by the same letters.

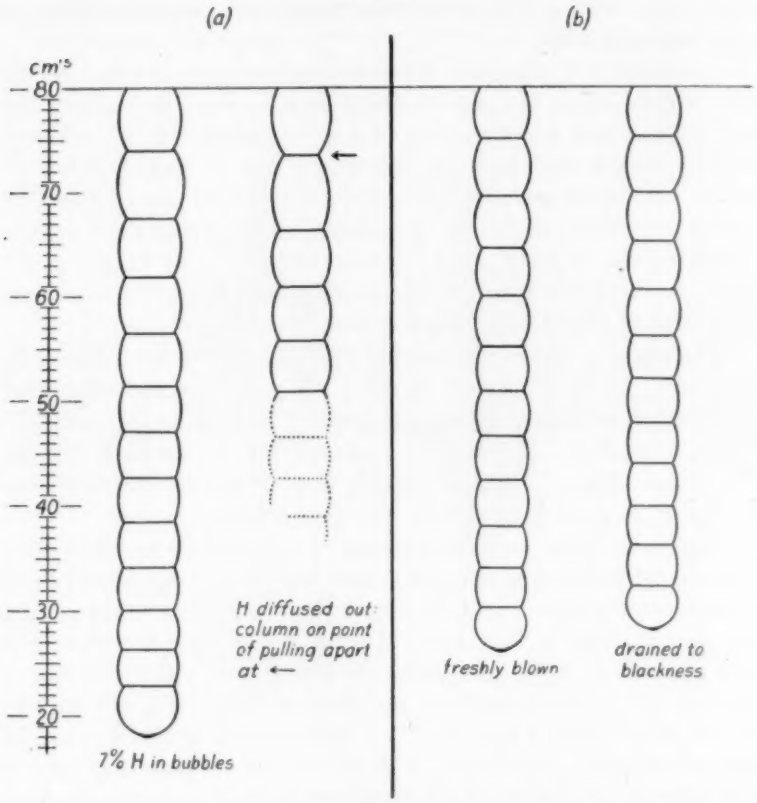
From the upper horizontal edges of the cube there also spring four triangular films in two pairs, matched on opposite sides; those from the side edges A D, B C, Fig. 27 (*c*), go down to the central hexagon at *a* and *b*, Fig. 27 (*a*), while those from the front and back edges A B, D C, join up to the kite-shaped plane at *d* and *e*, Fig. 27 (*b*). The four films are thus shown in Fig. 27 (*c*) by A D *a*, B C *b*, and A B *d*, D C *e*. The same is repeated from the four lower edges of the cube, A′ B′, B′ C′, etc. There then remain two pairs of quadrilateral films linking the kites and the hexagon to the triangular films from the edges. These last are represented by A *d c a*, B *d c b*, in Fig. 27 (*a*), and C *e c b* in Fig. 27 (*c*); the other would be D *e c d* behind C *e c b*. The same is repeated on the lower edges.

The whole complex thus numbers 31 films: 12 from the cube edges, 8 from the pyramid edges, and 8 quadrilateral films, together with the kite-shaped pair and the irregular hexagon forming the backbone of the figure.

EXTENSIBILITY OF COLUMNS.

When groups of bubbles are first formed the films of which they are constituted are rather thick, because as a rule the segments are not expanded to any great size. Owing, however, to the free drainage down the intersecting channels, the excess liquid rapidly

FIG. 28.



accumulates in the lower segments, and the weight thus localized distorts or breaks the group.

Some measures were therefore made of the elongations produced by added weights in various forms. In a single column it can be seen that the upper segments are longer than those lower down; with additional loading the extension increases until parting takes place. This is illustrated in Fig. 28 (which is drawn to scale). A column of 13 bubbles is shown at (*a*) when freshly blown with air

containing 7 per cent. of hydrogen. After the hydrogen had diffused out for five minutes, the loss of buoyancy produced the sag shown in the second drawing (*a*), taken when rupture was imminent between the first and second segments; the measurements could not, therefore, be completed. The ratio of length to breadth of the longest segment (on the point of instability) is 1.17 to 1. Comparative measures are also shown in the drawings (*b*) of the considerable contraction that takes place in an air-blown column between its early condition when uniformly colored, with all superfluous liquid removed, and its final condition of complete blackness, and therefore minimum mass. The successive heights of the segments in a column half an hour after blowing (uniformly colored, no excess liquid) were, counting from the top, 5.1 to 5.2 cm. for the first four; then in succession, 5.0, 4.8, 4.3, 4.2, 4.0, 3.8, 3.2—at which point contact was made with a larger segment on a fixed support.

The long glass cylinder in Fig. 6 was chiefly used for these measurements. The sliding support rod was adapted for manipulating a separate light glass ring, on which small weighed pieces of steel wire could be hung. A graduated pull could be exerted by a small solenoid below. Tiny horizontal magnets were attached to the columns, and by their tendency to set in the meredian were able to retard irregular oscillations. For this purpose they were fixed to light cotton rings by being soaked in nitro-cotton solution and dried.

A column of six segments each of 150 c.c. was elongated by one-third of its length with a weight of 0.136 gram; the original length, free of superfluous liquid, being 31.0 cm., and the maximum elongation, 11 cm.; the smallest additional weight then broke the column. The same weight, hung on a column of five bubbles 23 cm. long, caused an elongation of 8.3 cm., or 35 per cent. On the removal of a drop of liquid weighing 6 centigrams a contraction of 2.3 cm. followed.

A column of three segments gave the following result: With a weight of .075 gm. its initial length was 14.7 cm., and the elongation produced was 1.35 cm.

The following values were obtained from the gradual increase of load when a loss of buoyancy occurred by diffusion of hydrogen from a column of eight equal segments of 150 c.c. blown with 7 per cent. hydrogen. The initial length of 35 cm. was increased to

39.5 cm. when a weight of 7.5 centigrams was hung on. When the hydrogen had diffused out the total length became 40.3 cm., or an extension of 0.8 cm. from an additional weight of 8.4 milligrams. These results are recorded in the following table (I).

TABLE I.

n	l	w	e	wl	x	wl/x	E
	cm.	gm.	cm.				
6	31	.136	11	4.22	.355	11.9	.383
5	23	.136	8.3	3.13	.361	8.7	.377
5	23	.136–.006	8.3–2.3	2.99	.261	11.5	.498
3	14.7	.075	1.35	1.10	.092	12.0	.817
8	35	.075	4.5	2.63	.129	20.4	.583
8	35	.0834	5.3	2.92	.152	19.3	.552

Where n is the number of segments in the column; l is its length in cms.; w is the attached weight in gms.; e is the elongation in cms.; x is the elongation per unit length of column; and E is the corresponding value of Young's modulus.

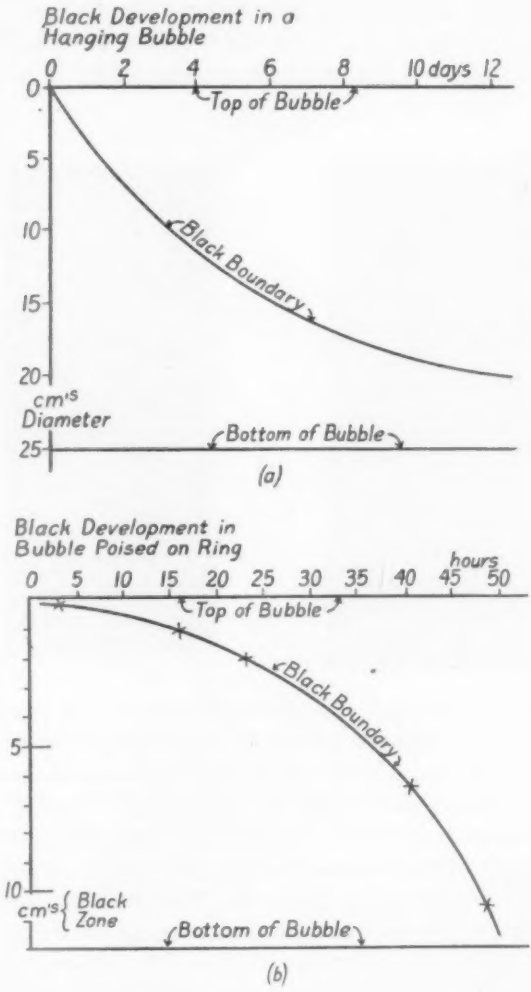
It will be noticed, on comparing the fourth set of these observations with the first set, that (roughly) halving the weight and length reduced the elongation per unit length to one-fourth, as might be expected. For, $x = \frac{e}{l}$ and $W = E\frac{e}{l}$, hence for the first case $W\,l = E\,e$; for the second case, $W'\,l' = E'\,e'$, or $W\,l = 4\,E'\,e'$. $\therefore 4\,E'\,e' = E\,e$. Now in the Table I, $E' = .817$, $E = .383$, or approximately $E' = 2\,E$, hence the last expression becomes $8\,e' = e$, or in terms of x, $8\,x'\,\frac{1}{2}\,l = x\,l$, whence $4\,x' = x$.

GAS TRANSFERENCE THROUGH FILM COMPLEXES.

Columns and clusters of bubbles generally reach the "black" stage with great rapidity by the action of the channels (Gibbs rings) of liquid where segments join together. The black development of an ordinary hanging bubble is different from that of a similar bubble resting on a ring, because in the latter case the action of the Gibbs ring is to assist gravity in withdrawing liquid from the film and thus to accelerate the thinning process, while in the former case the action of the Gibbs ring is against gravity, and thus retards the withdrawal of liquid from the film. The two curves in Fig. 29 show this difference very clearly: The black boundary on the poised bubble descending at an ever-

increasing rate, as it approaches the Gibbs canal present on the support ring; while in the hanging bubble the rate of fall continually decreases. (This is more noticeable when liquid is allowed to

FIG. 29.

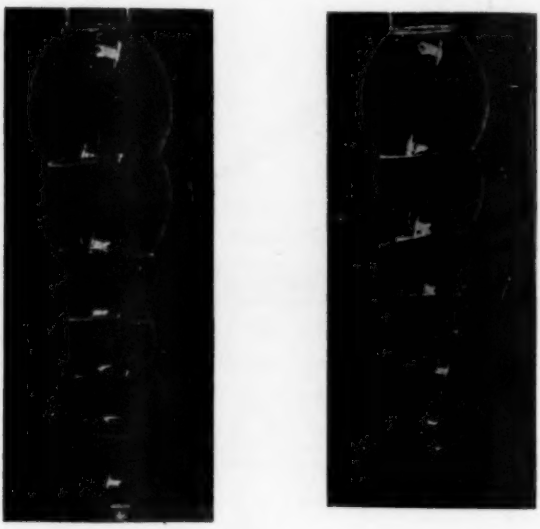


accumulate below while the thin black area extends downward. In the absence of suitable drainage, the colored zone then becomes continually thicker.) When, however, a bubble was provided

with two Gibbs rings, one above and one below, the rate of fall of the black boundary was almost linear for the greater part of the time.

This was arranged by attaching a small bubble under a large one, supported as usual from a nozzle above. The small bubble was kept steady by a smaller glass ring underneath. The nozzle was 8.3 cm. in diameter, and the size of the small attached bubble was adjusted so that the diameter of the Gibbs ring of contact

FIG. 30.

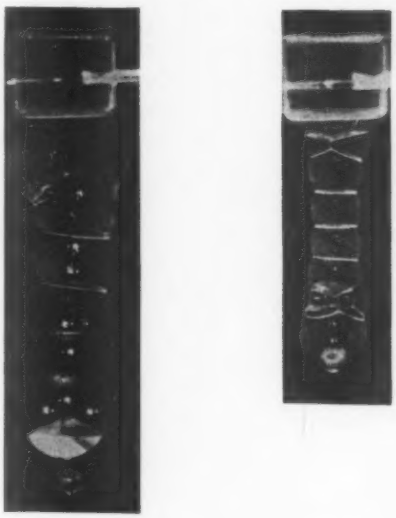


between the two bubbles was about the same. The greater bubble was 40 cm. high between the equal Gibbs rings top and bottom, *viz.*, where contact was made with the nozzle above, and the small bubble film below. The graph of "black fall" plotted with time was very nearly straight for 2½ days, by which time the black area had extended over three-fourths of the surface. After this it spread more slowly, and took another day and a half to reach the lowest point. The form was therefore intermediate between curves (*a*) and (*b*) of Fig. 29.

Now, in the more complex clusters there are many channels all connected at various inclinations, therefore not only is any excess liquid quickly discharged, but the films themselves are quickly drained to the "black" state.

This is the most favorable condition for the study of gas transference, as the film is then at its minimum thickness. The resulting contraction has been measured in the case of straight columns and other complexes by photographs taken periodically. These afford direct evidence of greater rate of transference in the smaller bubbles; for when records are taken of a column of unequal segments it is easily seen that the initial inequalities are accentuated as time goes on. Figs. 30 and 31 are reproductions from photographs of

FIG. 31.



two small columns at intervals of nine and seven days respectively; the volumes of the segments varied from 30 to 100 cm.

Large black volumes were more difficult to deal with on account of irregular oscillations; their relatively small mass when black was insufficient to stabilize them against any local convection. For example, in the 200 litre globe already described a column was blown consisting of six segments, the upper five of which had each a capacity of 1½ litres, while that of the lowest was 3 litres. In one day it became wholly black with the exception of a thick colored area that extended up over 30 per cent. of the lowest bubble, the weight of which was sufficient to keep the whole hanging vertically, although some of the junction planes were slightly inclined. By the sixth day the color had diminished to a zone 5 cm. wide.

This reduced load could not keep the column straight, and some of the oscillations that occurred displaced the drop on the lowest bubble as much as 15 cm. from the vertical, while a vertical contraction of 15 mm. had accrued, followed in the next two days by a further contraction of 6½ mm. The colored zone was now a disc of 2 cm. diameter, and the column had become so curved that an unusually large oscillation caused the lowest bubble to touch the globe, with the result that only the two uppermost segments remained, the junction plane between them being inclined at 30° to the horizontal.

A light glass ring was therefore arranged below to keep the column stationary. It was sealed to a 3 mm. glass rod bent round in a bow, roughly to follow the contour of the globe, and then secured to a vertical glass rod that could slide air-tight in the rubber stopper at the neck. The contraction of the column due to the gas transference, however, went beyond the limits through which the glass rod could be raised. The segments therefore became thinner and more strained, until on the eighty-ninth day separation took place between the third and fourth. The glass ring thereupon relaxed a distance of 8 mm., the amount by which the glass bow had been strained by the pull of the black column.

In some cases the various segments were measured daily by a cathetometer and horizontal sliding telescope. If D is the diameter of a bubble segment at the equator, and d the diameter of the plane circular ends, while h is the height, then the volume is given by

$$V = 1.0472h\ (0.4\ D^2 + 0.2\ Dd + 0.15d^2).$$

When the segment is unstrained, $d = D - 0.268h$, so that

$$V = 1.0472h\ (0.75\ D^2 - 0.130\ Dh + 0.01h^2);$$

only D and h need therefore be measured.

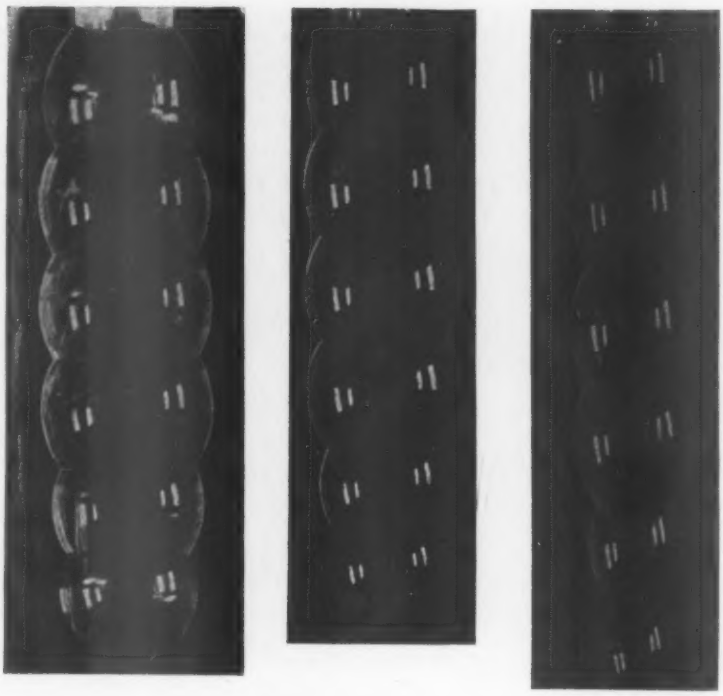
These relations were found to agree very well with the dimensions of segments of known volume.

The area of the curved surface through which the gas transference takes place (there being practically no loss through the plane ends) is given for a bubble whose centre of curvature is not in the axis of revolution by

$$S = \frac{\pi^2}{3} Dh - \left(2\frac{\pi^2}{3} - 2\pi\right) h^2 = 3.289\ Dh - 0.295\ h^2.$$

It must be noted that an uncontracted bubble segment has been assumed. This, however, was no longer the case when it became necessary to fix the column at both ends (to a nozzle above and a glass ring below). As the contraction proceeded therefore the total length did not alter, so that h remained practically the same

FIG. 32. FIG. 33. FIG. 34.



throughout; but as the segments shrank D and d continually diminished. Three illustrations of this are shown in Figs. 32–34. They are taken from a column of six bubbles in the 200 litre globe already described. The four top bubbles were of equal volume, while the two lowest were half the volume of the others. The third segment being between two similar ones remained symmetrical to the end, and thus gave more reliable results. The contraction finally resulted in the column pulling apart between the fifth and sixth bubbles on the sixty-fourth day. The upper five were thus left free, but the oscillations were so persistent that only

a blurred photograph was possible; this was, however, sufficient to give some measures of the free segments for comparison with those obtained when strained. Fig. 32 was taken at the start, Fig. 33 on the sixteenth day, and Fig. 34 on the sixty-fourth day before partition took place.

The volumes and surfaces for the third segment selected for calculation were as follows (Table II):

Black Six-Bubble Chain.

TABLE II.

DIMENSIONS OF SEGMENT (3).

Time	1 (Fig. 32)	16 (Fig. 33)	64 (Fig. 34)	Days
Volume	1133	1029	543	c.c.'s
Curved Surface	360	350.5	258	$(cm.)^2$

TABLE III.

AIR TRANSFER THROUGH SEGMENT (3).

Volume	1000	750	650	600	c.c.'s
Curved Surface	346	305	288	279	$(cm.)^2$
Rate of Transfer.. c.c's	7.6	11.3	14	16	through whole surface
Rate of Transfer.. per day	0.022	0.037	0.049	0.059	per $(cm.)^2$
Volume Contraction	0.76	1.51	2.15	2.67	per cent. per day

When the values were plotted with time, contraction curves were obtained for both volume and surface. By taking tangents to the volume and time curve at successive intervals of time, the corresponding rates of gas transference $\frac{dV}{s}$ were deduced.

The third segment thus gave the values shown in Table III for air transference through the black film composed of $3^1/_3$ per cent. ammonium oleate and 33 per cent. glycerin.

Three sets of these columns in the 200 litre globe were tried. The first was the largest in volume and took 101 days to pull apart. Figs. 35 and 36 show the appearances at start and finish, the total length meantime had been reduced from 53.3 to 50.9 cm.; after this the free bubbles remained on the nozzle a further 53 days. They were then replaced by the second set already described, which took 64 days before it divided. The third set which followed was more uniform, consisting of one segment, top and bottom, each of

whose volumes was half a litre, while the four in the middle contained one litre each. This set parted in 40 days.

Very good black columns were also obtained in the long glass cylinder (Fig. 6). With this it was possible to prevent undue straining of the segments by carefully raising the support ring

FIG. 35.

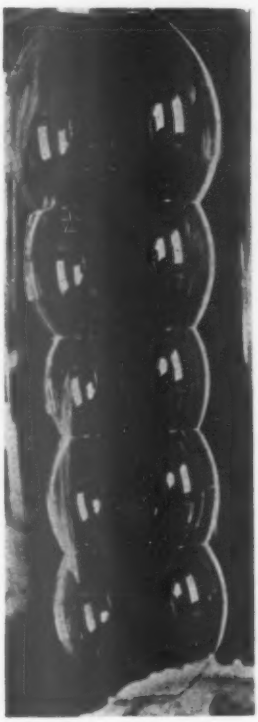


FIG. 36.

when necessary. The cylinder was long enough to get in ten segments each of over 250 c.c. A thin thread of stranded cellulose (artificial silk) was sometimes fixed both at the nozzle and support ring to lie along the outer contour of the column from top to bottom. This not only stabilized the column while being blown, but accelerated the drainage and black development, because any excess liquid in the Gibbs ring channels of the junction planes was quickly drawn into the capillary canals of the silk. The result was that the black stage was complete in one day, and there was entire

absence of any deformation from superfluous liquid remaining in the junction rings. One set took 47 days before the shrinkage caused the segments to part, the support ring not having been raised. The ratio of length to breadth of the equal segments two days before this occurred was 1.5 : 1, as compared to 1.17 : 1 in a similar colored column of like dimensions, but without any cellulose thread, and dragged apart by loading (see Fig. 28).

The segment volumes of another set diminished during the first fortnight from 270 c.c. to 225 c.c., and the curved surfaces from 145 to 120 square centimetres. The calculated rates of air transference obtained from the contraction curves are given in Table IV; the solution used contained 5 per cent. ammonium oleate and 50 per cent. glycerin.

TABLE IV.

Volume	265	250	235	c.c.'s
Curved Surface	143	139.5	136	$(cm.)^2$
Rate of Transfer (c.c.'s per day)	1.83	3.62	5.24	through whole surface
	0.013	0.026	0.039	per $(cm.)^2$
Volume Contraction	0.69	1.45	2.23	per cent. per day

Much higher values were given by a black column of five equal segments, initially 161 c.c., very completely drained by two cellulose strands on opposite sides of the bubble contours. No glass ring support was employed, so the column contracted freely without the segments being strained out of their normal curvature. In four days the volume diminished 30 per cent. The mean rate of air transference being nearly 11 c.c. per day when each segment had a volume of approximately 125 c.c. The corresponding value of the curved surface was about 80 $(cm.)^2$, so that the loss through unit area was 0.14 c.c. per day. The solution used for this contained 1 per cent. ammonium oleate to 10 per cent. of glycerin.

GAS DIFFUSION THROUGH BLACK FILMS.

The rate at which gases diffuse through liquid films was found to be very much greater than the slow escape caused by the small excess-pressure by which bubbles are distended. The latter only

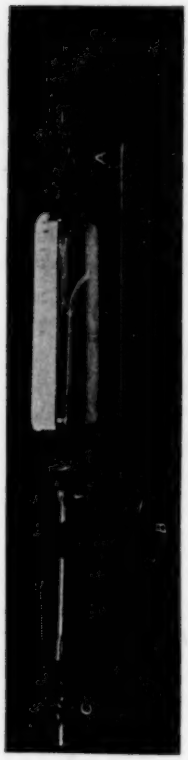
becomes appreciable some days after the black stage is reached; but if a thick colored air bubble has a small percentage of hydrogen blown into it, a contraction takes place in a few minutes; or, conversely, an expansion is quickly produced by circulating some hydrogen in the closed vessel in which the bubble is hanging. In the same way when a plane film was formed across a cylindrical vessel containing only air and some soap solution, and hydrogen was then circulated in the space between the film and the neck, a steady movement of the film towards the neck at once began; the hydrogen passed through to the enclosed space beyond the film more quickly than the contained air diffused out. The reverse process was easily carried out by first filling the bottle with pure hydrogen, and expanding the film as before. A current of clean air was then circulated on the same side of the film as before; the resulting movement of the film was now away from the neck, because the volume enclosed beyond the film lost hydrogen more quickly than air could diffuse in. When oxygen was used instead of air the motion was more rapid.

When these experiments were made after the black stage was reached, the diffusion was sufficiently rapid to cause a large distortion of the plane film, due to partial adhesion round the periphery of the film, although the glass walls had previously been well moistened. For the laboratory measures of the relative diffusion rates of various gases, an 8 litre bottle, 19 cm. in diameter, was calibrated, and the movements of the film (which would thus have an area of some 300 cm.^{2}) were noted for successive small time intervals. The stopper was fitted with inlet and outlet tubes, of which the former was long enough to reach the bottom, and could also slide easily in an air-tight fitting. The film was thereby started by pushing the inlet tube down into a small quantity of soap solution in the bottle, and then withdrawing it gradually as the gas current expanded it to the desired position. The tube was then pulled just through the film, the current nearly shut off, and the whole left to settle until the black zone had developed sufficiently in the firm. The gas to be circulated was then connected and turned on, and the movements of the film noted. The end of the outlet tube was kept within a cm. of the film surface to maintain a thorough circulation.

With hydrogen in the vessel, and when the film was half black and half silvery (next in thickness to black), and air was circu-

lating at 130 c.c. per minute, the volume enclosed by the film decreased at a fairly uniform rate of 1 litre in 20 minutes. After this movement became slower as the percentage of hydrogen diminished in the space beyond the film. Finally, 5.70 litres of hydrogen originally present were found to be replaced by 1.40 litre of air. In another experiment, with the firm almost completely black, 6.23 litres of hydrogen diffused out and were replaced by 1.35 litre of air.

FIG. 37.



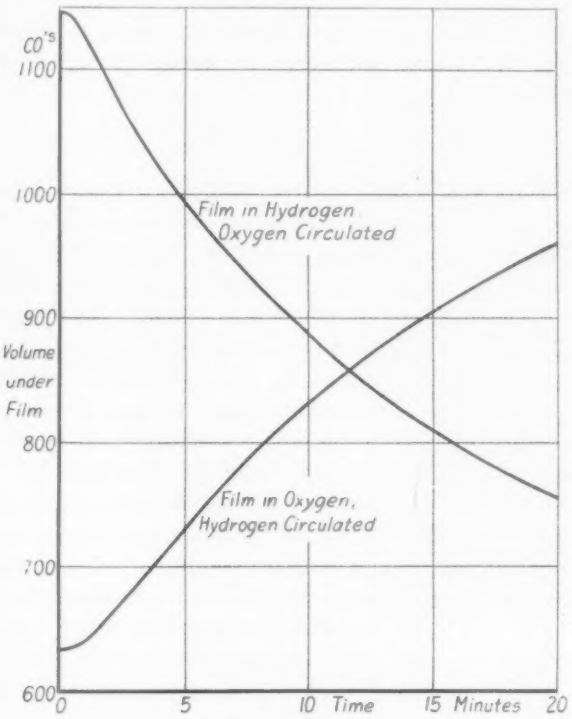
The maximum rate of diffusion could not be realized in this wide vessel because of the film distortion that was produced when the rate of circulation was increased. To overcome this a vessel only 8.5 cm. in diameter was used. (Fig. 37), in which the ordinary stopcock was replaced by a two-way cock A, while an inlet and outlet fitting was fixed in the rubber stopper. The outlet tube as before could slide easily in its air-tight neck. The vessel was filled with hydrogen coming in through A and leaving at B. The film was obtained (after first moistening the walls of the vessel) by tilting a drop of the soap solution into the neck at A. The gas entering there at once formed a film and pushed it along to the desired position. A was then closed and the film left to become black. Meanwhile a small current of hydrogen was continued through B and C to prevent any subsequent disturbance of the film, such as by an alteration of temperature.

Before starting the air or oxygen current through B and C the film was lubricated by a slow complete revolution of the vessel, whereby the small amount of liquid inside flowed all round the walls. This caused some diminution of the black area, which was measured and allowed for. During the subsequent diffusion the sliding tube was adjusted so that its open end was kept within a centimetre of the moving film. Small measured samples of the mixed gases behind the films were withdrawn at intervals for analysis through the two-way cock A.

The maximum rate of diffusion of hydrogen above that of air was found to be 42 c.c. per hour per cm^2. When oxygen was used

instead of air the value obtained was 50 c.c. of hydrogen per hour per cm.^{2} greater than the oxygen going the other way; and 1145 c.c. of hydrogen passed out, while 632 c.c. of oxygen went in. When the reverse process was tried 1173 c.c. of hydrogen went in through the black film, while 635 c.c. of oxygen diffused out. The

FIG. 38.



Hydrogen Oxygen Diffusion through Black Film

two operations involved the passage of the film 7 cm. along the cylinder in the first case, and the same back again for the reversal. Fig. 38 gives the graphs of the movement of the film, and shows the variation of the enclosed volume, with the time. The rate of relative diffusion at any time is given by the slope of the tangent to volume-time curves. This was found to decrease as the proportion of oxygen under the film increased.

The contraction of bubbles in air when blown up with from

10 per cent. to 30 per cent. of hydrogen was measured in order to deduce the diffusion rates through colored films. A much lower value was obtained; thus a bubble colored steely blue to pale amber and containing 16 per cent. of hydrogen showed a rate of contraction of approximately $^2/_3$ c.c. per hour per cm^2. Measures were also made with half bubbles blown on the roof of a glass chamber in which a proportion of hydrogen was circulated; and also by comparing the contractions of similar bubbles when hanging from a nozzle and resting on a ring. This last was done to correct for the distortion of figure produced by the buoyancy of the contained hydrogen.

HYDROGEN BUBBLES BLOWN UNDER SEVERAL ATMOSPHERES.

Bubbles that have thinned to blackness contract at an ever-increasing rate by the continual transference of the enclosed gas through the envelope. It was mentioned in last year's Discourse that the contraction is greatly retarded when the bubbles are formed in an enclosure in which the pressure has been raised, the excess-pressure distending the bubble becoming then of relatively smaller proportion to the total pressure. Further experiments have shown that a black bubble in hydrogen under 6.3 atmospheres pressure took 100 days for its diameter to contract from 7.7 to 4.0 cm., whereas only 7 to 10 days is needed for the same contraction to take place in a similar bubble at atmospheric pressure. When air was used instead of hydrogen the difference was equally marked; thus an 8 cm. bubble in a vessel charged to 7 atmospheres took 4 months to diminish 1 cm. in diameter, the same contraction at atmospheric pressure taking only about 14 days.

Suitable vessels for these measurements are afforded by the strong glass bottles used to hold sulphurous acid. A screwed brass collar was cemented to the neck, and to this a brass T-piece was secured by a gas-tight union. The glass nozzle for supporting the bubble was cemented into the vertical arm of the T-tube, and sealed to a thick glass bulb above bent over horizontally to hold some soap solution. The gas used was admitted by the valved horizontal arm of the T-piece, a hole being made at this level into the inner glass tube to give access through the nozzle, which had a diameter of about 1 cm. (Fig. 39), just within its lower end a constriction was formed. The apparatus was tested and found tight under 10 atmospheres pressure.

The pressure was first adjusted to about 6 atmospheres, and a drop of soap solution was decanted into the constriction; on admitting more gas a bubble was expanded on the nozzle and the pressure thereby raised to 6½ atmospheres. The black stage then developed very much as usual, and the gas transference was determined by periodic measurements of the contraction.

FIG. 39.

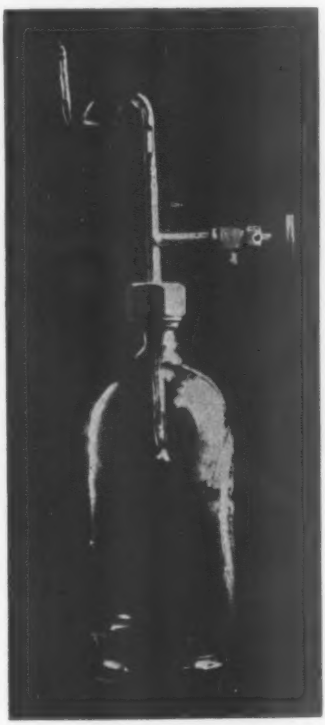


Table V gives the rate of transference obtained in hydrogen at 6½ atmospheres compared with the values at 1 atmosphere. The numbers given are calculated for diameters of 4, 6 and 8 cm. The second column gives the internal excess pressure P of the soap bubble (in mm. of water) measured at atmospheric pressure. The proportion F of this to the total pressure in the bubble vessel is shown in the third column (in units of 10^{-6}) both for 1 atmosphere and 6½ atmospheres. The observed rates of gas transference R are similarly shown in the fourth column.

Thus it may be said that the longevity is increased in the proportion of the numbers given in the last two columns, in this case, approximately as the square roots of the relative pressures under which the bubbles were blown.

TABLE V.

Diameter cm.'s	P mm.'s H_2O	F×10^{-6}		R c.c.'s	
		(*a*) 1 atm.	(*b*) 6.5 atm.	(*a*) 1 atm.	(*b*) 6.5 atm.
4	0.330	32.16	4.80	0.22	0.0825
6	0.220	21.44	3.20	0.14	0.041
8	0.166	16.08	2.40	0.10	——

For experimental assistance I have to thank W. J. Green, B.Sc., and for reading the proofs and checking the calculations I am indebted to J. D. H. Dickson, M.A., Senior Fellow of Peterhouse College, Cambridge.

Specific Gravity of Orthophosphoric Acid. N. P. KNOWLTON and H. C. MOUNCE (*Jour. Ind. and Eng. Chem.*, 1921, xiii, 1157–1158) have determined the specific gravity of aqueous solutions of orthophosphoric acid at 25° C. compared to water at 25° C. The twenty-four solutions used by them ranged from 3.39 per cent. orthophosphoric acid with a specific gravity of 1.0187 to 90.26 per cent. orthophosphoric acid with a specific gravity of 1.7558. From the plotted curve of their results they have prepared a table, giving the specific gravity of aqueous solutions of orthophosphoric acid for each per cent. of the acid from 1 per cent. to 91 per cent., both inclusive.

J. S. H.

Separation of Sucrose from Glucose. LEON A. CONGDON and CHARLES R. STEWART, of Syracuse University (*Jour. Ind. and Eng. Chem.*, 1921, xiii, 1143–1144), have tested the solubility of these two sugars in various organic solvents, using an ordinary Soxhlet extraction apparatus. The sugar was placed in the paper thimble, and the solvent was heated for five hours. When one gram of dry sugar and 100 c.c. of ethyl acetate were used, glucose was almost completely extracted, while sucrose was but slightly affected. When a mixture of equal parts of glucose and sucrose was used, an almost complete separation of the two sugars was obtained. On cooling its solution in ethyl acetate, glucose (dextrose) separated in the crystalline form.

J. S. H.

Proposed Translation of Helmholtz's "Handbuch der physiologischen Optik." James P. C. Southall, President of the Optical Society of America, invites subscriptions to a fund to translate into English the last edition of Helmholtz's great work, which still remains the leading authority in the field. In addition to the value of the work in a form in which its text will be accessible to many who do not read the original language, the publication will neatly mark the centennial anniversary of the birth of the great scientist, whose influence has been felt as deeply in modern scientific thought as that of any of his distinguished contemporaries. It is estimated that the cost of translating and publishing the volume will be at least $5000. Contributions in any amount may be sent to Adolph Lomb, treasurer, care of the Bausch and Lomb Optical Company, Rochester, New York. A subscription of not less than $15 will entitle the subscriber to a copy of the complete work.

H. L.

THE CRYSTAL STRUCTURES OF THE COMMON ELEMENTS.*

BY

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INTRODUCTION.

By crystal structure is meant the exact relative location of and distances between atoms in solid bodies. The crystal structure of a substance is known only when an exact model of it can be constructed to scale, showing all the atoms in their positions. A knowledge of the shape or size of the atoms is not generally included in the definition, but the experiments on crystal structure give some information regarding size and shape, which will be briefly discussed. Many experiments now in progress are sure to yield more evidence on this subject.

The microscope by which these atomic measurements are made is an X-ray instrument, constructed on the principle of the spectroscope, rather than the microscope. It is used to measure the distance between planes of atoms, in exactly the same way as a grating spectroscope is used to measure, by means of a known wave-length of light, the distances between the lines of an unknown grating. In the case of the X-ray spectroscope the registration must, of course, be photographic or electrical (ionization), not optical; except when sufficient intensity is available to make a fluorescent screen luminous, and so indirectly allow visual reading. The fundamental difference between this X-ray spectroscope and the ordinary spectroscope is that the X-ray grating is a crystal which is three-dimensional instead of two-dimensional, and has to be placed at exactly the right angle in order to operate. This is the cause of the special technique of X-ray crystal analysis, which will be briefly outlined below.

The X-ray spectroscope measures the distance between planes of atoms, in any desired direction. This is all that is needed, in simple cases, for the construction of the crystal model. For it is

* Presented at a meeting of the Section of Physics and Chemistry held Thursday evening, November 10, 1921.

evident that if three sets of planes can be constructed, in different directions, each set including all the atoms in the crystal, their intersections will give all the points at which atoms can be located. The only question remaining is *how many* atoms are located at each point. If the density of the crystal requires that this number cannot be greater than one, and the symmetry requires that every point shall be occupied by an atom, *i.e.*, that the number cannot be less than one, then the analysis is complete. This is the case with all the pure elements analyzed thus far, except bismuth. Although three sets of planes are sufficient, many more are usually observed in order to strengthen the evidence and increase the precision.

In case more than one atom, *i.e.*, a group molecule, is located at some of the points, as is probably the case with electronegative elements like sulphur and selenium, and with most compounds, the X-ray spectroscope is able to give evidence of this fact by the *intensity* of the diffraction images. Such intensity measurements were used in the analyses of several of the compounds recorded in Table 2. It is from these intensity measurements, also, that we hope for the greatest evidence regarding the shape and size of atoms.

SCOPE.

X-ray crystal analysis is still in its infancy. Only 35 of the 87 known elements have as yet been analyzed, and four of these analyses, Li, Bi, Sn and Ce, are incomplete. The 31 complete analyses include nearly all the common metallic elements. These analyses are complete only in the limited sense that the arrangement of the atoms and the distances between them have been determined, with an accuracy of about ½ per cent., at room temperature. They are incomplete with respect to polymorphic arrangements that appear at other temperatures, and are of course incomplete in the sense that they do not tell all that can and will be learned from X-ray crystal analysis about these elements, especially the shape and structure of the atoms. Investigations to obtain further information of this kind are already in progress in many laboratories, notably those of the pioneers of X-ray crystal analysis, W. H. and W. L. Bragg.

In addition to these 34 elements, 42 binary compounds have been analyzed, and 10 more-complicated ones.

In spite of the small number of these analyses the information

which they furnish is so closely related to other chemical and physical properties of atoms that it cannot fail to be useful. The extent to which it is used will depend upon its availability. It is the purpose of the present paper to collect and summarize this data in the hope of making it more available.

METHODS.

The methods of X-ray crystal analysis have been so well and so frequently described that only a summary need be given here, with a brief discussion of some of the more recent developments. For details the reader is referred to the excellent description by the originators of X-ray crystal analysis, W. H. and W. L. Bragg,[1] and the recent articles of Debye and Sherrer [2] and the author.[3]

The principle underlying all the different so-called methods of X-ray crystal analysis is the same. It consists in observing the angles at which X-rays of a known wave-length are reflected by the planes of atoms in the crystal, and so calculating the distance between these planes; and then constructing a model having these planar spacings. The different methods are occasioned by different ways of mounting the crystal, which necessitates different procedure in interpreting the results.

A. Laue Method.—A *single* crystal, which may be very small, is mounted in a *known* orientation, and illuminated with a narrow beam of *white X light, i.e.,* a beam containing all wave-lengths within a certain range. A photographic plate placed behind the crystal registers, in its centre, the primary beam which has passed through the crystal, and around this central image a large number of small spots. Each of these spots is caused by the reflection of some wave-length in the primary beam by one of the sets of planes in the crystal.

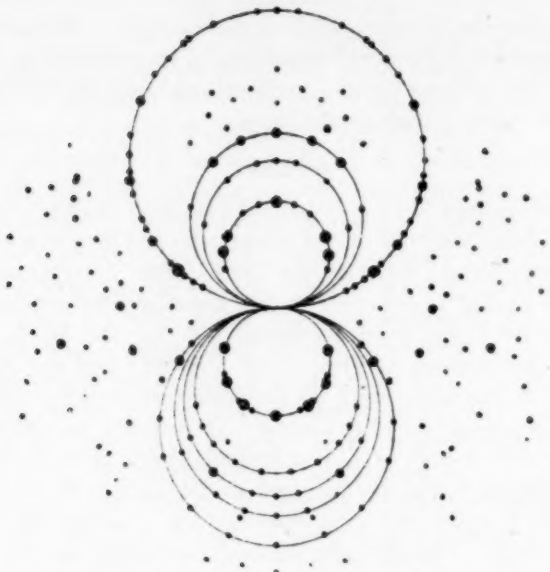
In order to interpret such a photograph it is necessary to determine what set of planes and what wave-length corresponds to each spot. These calculations are exceedingly laborious. The first crystal analyses by W. L. Bragg were made by this method, but it has led to only a few complete analyses. It is especially suited to qualitative investigation, because of the simplicity and speed with

[1] "X-rays and Crystal Structure," by W. H. and W. L. Bragg. G. Bell and Sons, London.

[2] Debye and Sherrer, *Physik Z.*, 17, 277, 1916; 18, 291, 1917.

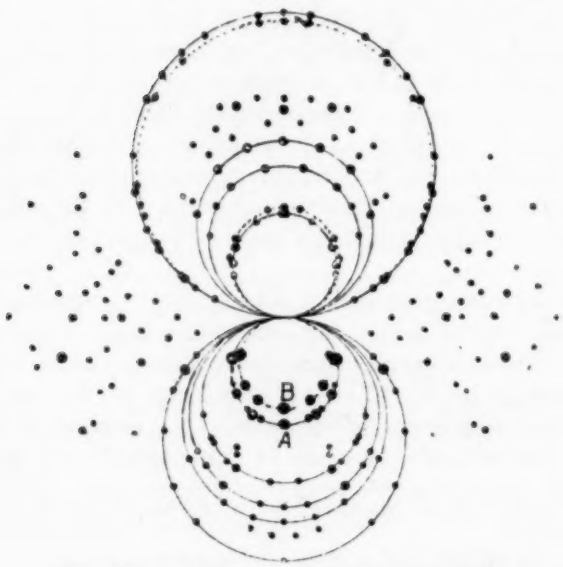
[3] Hull, *Phys. Rev.*, 10, 661, 1917; 17, 571, 1921.

FIG. 1.



Stereographic projection of Laue spots of adularia (001).

FIG. 2.

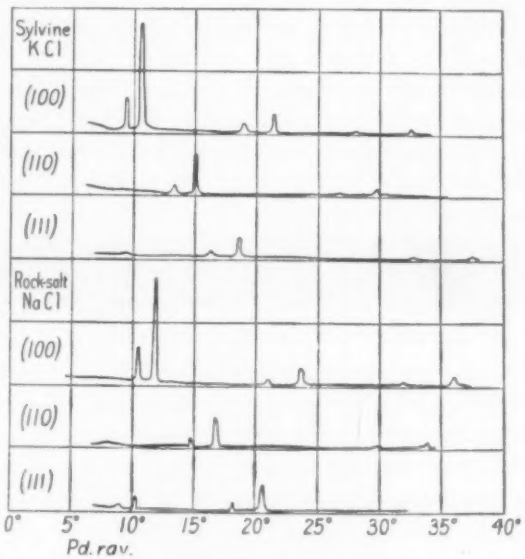


Stereographic projection of Laue spots of moonstone (001).

which the photographs can be taken. For example, Figs. 1 and 2 represent stereographic projections of Laue patterns [4] of two closely related feldspars, adularia and moonstone respectively. They show that moonstone consists of two distinct monoclinic lattices, corresponding to two different kinds of solid solution, whereas adularia is a single homogeneous solid solution.

Quite recently Wyckoff [5] has applied the Laue method with great thoroughness to the analysis of several crystals. It is prob-

FIG. 3.



Reflection of Pd. X-rays from different planes of sylvine and rock salt.

able, however, that the use of this method will be mainly restricted to supplementing other methods.

B. Bragg Method.—A narrow pencil of monochromatic X-rays falls on the face of a single crystal, and is reflected to an ionization chamber or photographic plate. Crystal and ionization chamber are rotated until the reflecting angle is found, first for one face and then another. The angle and intensity

[4] These figures are taken from a review of a paper of S. Kozu by Tutton in *Nature*, **108**, 352, 1921.

[5] Wyckoff, *Am. J. Sci.*, **50**, 317, 1920; *Phys. Rev.*, **16**, 149, 1920; *J. Am. Chem. Soc.*, **42**, 1100, 1920.

of reflection are recorded for each face, as shown in Fig. 3.[6] Since both the wave-length and the reflecting face are known, the model can be constructed at once for simple lattices; and complex structures can be interpreted if the intensity measurements are accurate.

This method, by far the simplest, is applicable only when single perfect crystals are available. Unsuspected twinning or distortion of the crystal will lead to false conclusions. In these cases the powder method offers a very simple check. There are a great many perfect crystals still unstudied, whose successful analysis awaits only time and experience in the interpretation of intensity of reflection.

C. Powder Method.—Instead of observing the reflections from different crystal faces one at a time, as in the Bragg method, one may register them all simultaneously on a photographic plate,

FIG. 4.

Powder diffraction pattern of rock salt.

by using a large number of small crystals, oriented at random. If the number of these small crystals is sufficiently large every possible reflecting position of the large crystal in the Bragg method will be represented simultaneously by one or more of the small crystals. The resulting photograph will contain, on a single film, all the reflections that could be obtained from the different faces of a single crystal. For example, a powder diffraction photograph of rock salt would be the equivalent of superimposing the three lower rows of Fig. 3, plus several more rows not given in the figure. Such a photograph is shown in Fig. 4.[7]

It is obvious that the reflections from different faces are so mixed in the photograph that one cannot tell, as in the Bragg method, which one belongs to each particular face. This makes

[6] From "X-rays and Crystal Structure," p. 89.

[7] Each of the reflections plotted in Fig. 3 consists of a pair of lines, one strong and one weak, due to the fact that the source of X-rays was not monochromatic, but consisted of two wave-lengths. The source used for Fig. 4 was truly monochromatic, the weaker component having been absorbed by filters. Hence only the strong reflections of Fig. 3 appear in Fig. 4.

it more difficult to construct the model. On the other hand, the powder photograph cannot lie. Twinning and distortion have no effect on it. Every set of planes in the crystal whose spacing is large enough to come within the limits of the photograph is represented by a line.

The construction of the model, though more difficult than with the Bragg procedure, is still very easy for simple substances. In the Bragg procedure the spacing of each set of planes is known from the experimental data, and the model is constructed with these definite dimensions. In the powder procedure the whole group of spacings, from the largest down to a specific value is known, and one seeks a model whose whole pattern of spacings fits the observed pattern. The fit must be exact, both in position and intensity. A single extra line, unless accounted for by a demonstrable impurity, invalidates the solution.

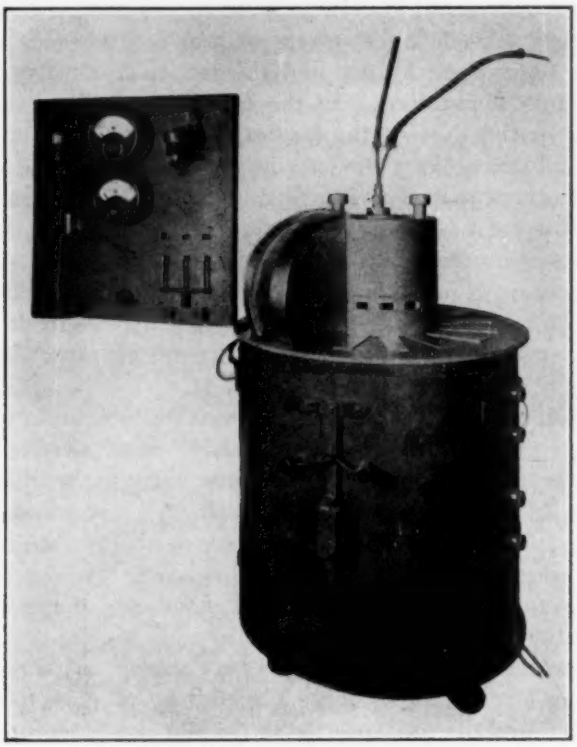
The process of taking and interpreting the powder photographs has been greatly simplified. The X-ray tube may be made to operate without attendance, and to take several photographs simultaneously. Fig. 5 shows such an equipment, adapted to operate from a lamp socket, to run continuously day and night without attention, and to take fifteen pictures simultaneously.[8] The operator is automatically protected from both X-rays and voltage, the transformer and high tension connections being entirely internal and the case grounded. The investigator is thus free to concentrate his attention upon the more strictly scientific parts of the investigation, *viz.*, the preparation of the material to be studied, and the reading and interpretation of the results.

The mounting of the material is very simple. It is reduced to fine powder by crushing or filling, placed in a thin glass tube 1 mm. in diameter, and the tube inserted in the slot provided for it in the cassette. When more convenient the powder may be mixed with a small amount of organic binder and spread on a narrow strip of paper or celluloid, and thin strips of metal or wires of the material to be tested may be used instead of powder in special cases. Massive lumps and moulded blocks have also been used with good results, the block being so mounted as to reflect the rays from its face. In the case of high atomic weight materials it is desirable

[8] A detailed description of this equipment is given by W. P. Davey in the November number of the *J. Optical Soc. of America.*

to mix the powder with some light amorphous substance, so as to reduce the total absorption of the rays, in passing through the sample, to about 50 per cent. absorption. Flour and corn starch have been satisfactorily used for this purpose.

FIG. 5.



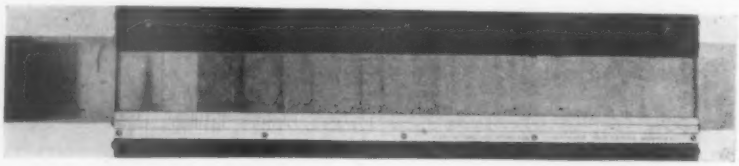
Apparatus for X-ray powder diffraction photography.

The reading of the film can be greatly facilitated when once the apparatus has been standardized. With a given wave-length and radius of film the planar spacings corresponding to the different lines on the firm are a function only of the distances of the lines from the trace of the undeviated beam. This function may therefore be laid off once for all on a scale, which may be used to read off planar spacings in angstrom units directly from the film, as shown in Fig. 6; or the scale may be laid off on a template, which

may be fastened beneath the film in the cassette, and so photograph a scale of angstrom units on the film during exposure, as in Fig. 7.

The interpretation of the powder patterns in the case of simple substances is straight forward and easy when the crystallographic system and axes of the substance are known. For complex substances the intensities of the lines must be measured. This can be

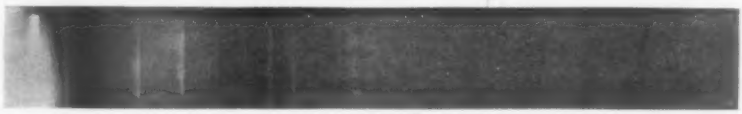
FIG. 6.



Scale for reading crystal spacings directly from powder diffraction pattern.

done with an accuracy of about five per cent. by an optical pyrometer or a photo-electric photometer, in terms of a series of steps of known ratios, photographed on one end of the film by the main monochromatic beam, through a stepped filter. These steps are produced by the same wave-length and in the same length of time as the lines with which they are to be compared. Hence the

FIG. 7.



Scale of crystal spacings photographed on powder diffraction pattern.

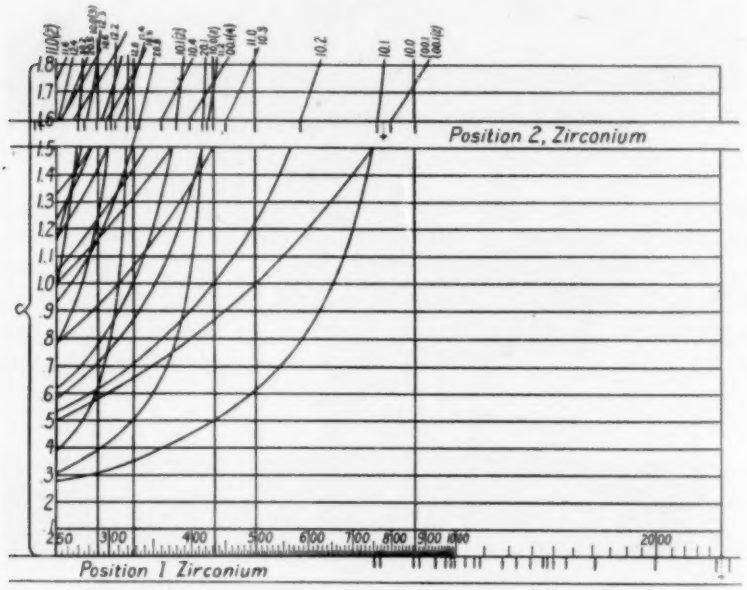
intensity measurements are independent of the law of blackening of the film and the development, except in so far as these may vary from point to point along the film. Quite recently W. H. Bragg has shown [9] that the powder reflections can be measured with an ionization chamber, in the same way as the reflections from a single crystal. This allows still greater accuracy in the measurement of intensities.

When there is no reliable crystallographic data about the substance under investigation the interpretation is in general very laborious. The procedure is to make guesses, and check them one

[9] W. H. Bragg, *Proc. Phys. Soc. London*, **33**, 222, 1921.

by one. When once the right guess is made its correctness is at once obvious, but an indefinite number of wrong guesses may have to be tried before finding the right one. Systematic mathematical methods of procedure have been suggested by Runge [10] and Johnsen and Toeplitz,[11] but have so far been applied only to the case of graphite. It is to be hoped that these methods will be found capable of application to crystals of low symmetry.

FIG. 8.



Graphical analysis of zirconium.

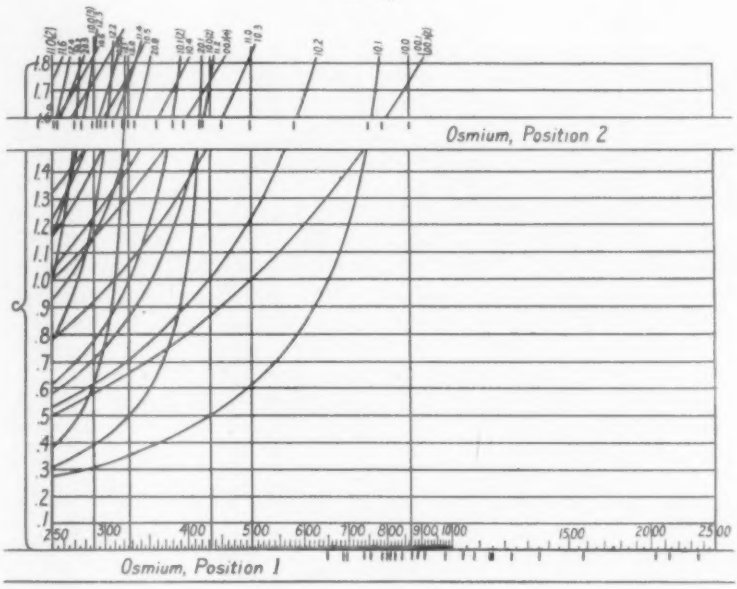
For uniaxial crystals the process of guessing may be greatly simplified by the use of plots, showing the possible planar spacings as a function of the axial ratio of the crystal.[12] The observed spacings are laid off on a strip of paper, which is moved systematically over the plot, comparing its pattern of experimental lines with the theoretical ones of the plot for each axial ratio. The process is one of guessing and check, as before, but the checking is

[10] Runge, *Phys. Z.*, **18**, 509, 1917.
[11] Johnsen and Toeplitz, *Phys. Z.*, **19**, 47, 1918
[12] Hull and Davey, *Phys. Rev.*, **17**, 549, 1921.

facilitated so that an entire crystal system may be gone over in a few minutes. Figs. 8 and 9 show the application of this method to zirconium and osmium.

The application of graphical analysis to crystal systems having more than one variable parameter, *i.e.*, to the orthorhombic, monoclinic, and triclinic systems, presents more difficulties, and a satisfactory method has not yet been found.

FIG. 9.



Graphical analysis of osmium.

EXPERIMENTAL RESULTS.

The results of the analyses of elementary substances that have been made thus far are summarized in Table 1, the elements being arranged in the order of atomic weights. The headings are self-explanatory, except for the two values given for the atomic diameter of some elements. These are the distances to the nearest atoms in the pyramid planes and basal planes respectively, corresponding approximately to the major and minor axes respectively of the solid ellipsoids of revolution which, if closely packed, would give the observed arrangement. The two values are inserted as a

TABLE I.

Crystal Structures of Elements.

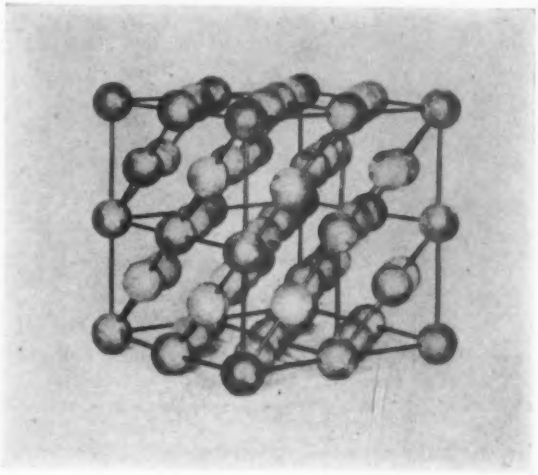
Substance	Crystal Structure		Latitce Constant Side of Elementary Cube or Hexagonal.	Closest Approach of Atoms	Authority
	Type of Lattice	Axial : Radio			
Lithium	Body-centered cube		3.50	3.03	Hull[1]
Carbon (diamond)	Tetrahedral cubic		3.56	2.06	Bragg[2]
Carbon (graphite)	Hexagonal	2.75	2.47	1.50	Debye[3] Hull[1]
Sodium	Body-centered cube		4.30	3.72	Hull[1]
Magnesium	Hexagonal	1.624	3.22	3.22	Hull[1]
Aluminium	Face-centered cubic		4.05	2.86	Hull[1] Sherrer[4]
Silicon	Tetrahedral cube		5.43	2.35	Debye[5] Hull[1]
Calcium	Face-centered cubic		5.56	3.93	Hull[6]
Titanium	Hexagonal close-packed	1.59	2.97	2.90 2.96	Hull[7]
Vanadium	Body-centered cubic		3.04	2.64	Hull[8]
Chromium	Body-centered cubic		2.895	2.508	Hull[9]
Iron	Body-centered cubic		2.86	2.48	Hull[1]
	Face-centered cubic		3.60	2.54	Westgren[10] Bain[19]
Cobalt	Face-centered cubic		3.554	2.514	Hull[9]
	Hexagonal close-packed	1.633	2.514	2.514	Hull[9]
Nickel	Face-centered cubic		3.540	2.505	Hull[1,9] Bohlin[11]
Copper	Face-centered cubic		3.60	2.54	Bragg[12]
Zinc	Hexagonal close-packed	1.860	2.670	2.920 2.670	Hull[9]
Zirconium	Hexagonal close-packed	1.59	3.23	3.18 3.24	Hull[7]
Molybdenum	Body-centered cubic		3.143	2.720	Hull[9]
Ruthenium	Hexagonal close-packed	1.59	2.686	2.640 2.686	Hull[9]
Rhodium	Face-centered cubic		3.820	2.700	Hull[9]
Palladium	Face-centered cubic		3.950	2.795	Hull[9]
Silver	Face-centered cubic		4.060	2.876	Vegard[13]
Cadium	Hexagonal close-packed	1.89	2.960	3.28 2.96	Hull[9]
Indium	Face-centered tetragonal	1.06	4.58	3.33 3.24	Hull[9]
Tin (gray)	Tetrahedral cubic		6.46	2.80	Bijl[14]
Antimony	Rhombohedral hexagonal	2.647	4.28	2.87 3.02	James[15]
Cerium	Hexagonal close-packed	1.62	3.65	3.64	Hull[7]
	Face-centered cubic		5.12	3.64	
Tantalum	Body-centered cube		3.272	2.833	Hull[9]
Tungsten	Body-centered cubic		3.150	2.726	Debye[16] Hull[9]
Osmium	Hexagonal close-packed	1.59	2.714	2.66 2.72	Hull[7]
Iridium	Face-centered cubic		3.805	2.690	Hull[9]
Platinum	Face-centered cubic		3.930	2.780	Hull[9]
Gold	Face-centered cubic		4.08	2.88	Vegard[17]
Lead	Face-centered cubic		4.92	3.48	Vegard[17]
Bismuth	Rhombohedral hexagonal		4.54	3.11 3.47	James[18]
Thorium	Face-centered cubic		5.04	3.54	Bohlin[11] Hull[7]

record of experimental results, independent of what the actual shape of the atoms may be.

The thirty-five elements in Table 1 represent five different types of atomic arrangements. They are designated respectively as face-centered cubic or cubic close-packed, body-centered cubic, tetrahedral cubic or diamond type, hexagonal close-packed, and rhombohedral.

The most common arrangement is the face-centered cubic type.

FIG. 10*a*



Model of face-centered cubic arrangement.

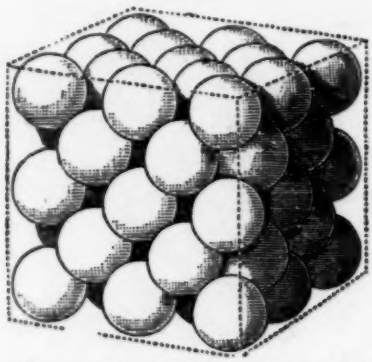
This arrangement is especially interesting because it is one of the two alternative arrangements which equal solid spherical balls assume when put into a box and shaken until they are packed as closely as possible. This arrangement is shown in Figs. 10*a* and 10*b*. The closest packed arrangement of spheres is obviously that which gives the maximum number of contacts between each sphere and its neighbors. In Fig. 10*b* each sphere touches twelve others.

Fifteen elements have their atoms arranged in this face-centered cubic or cubic close-packed arrangement; and it is worthy of note that they are all metals and all ductile. The ductility may reasonably be ascribed to the arrangement, and one may general-

ize tentatively as follows: Any substance which crystallizes face-centered cubic will be ductile.

For the purpose of visualizing this relation the type of lattice may be connected with the shape of the atom. The tendency of the atoms of certain substances to arrange themselves like closely packed solid spheres can best be pictured as due to the fact that the electrons in their outer shells are so symmetrically distributed and so closely coupled together [13] as to present toward other atoms an essentially rigid spherical shell, with very weak residual localized forces. These atoms are held together in the solid crystalline

FIG. 10*b*.



Cubic close-packing of solid spheres (face-centered cubic arrangement).

state, not by the sharing of electrons or secondary valence forces, but by free electrons wandering at random between the atoms, occupying on the average fairly definite positions. These free electrons are the electrons that are superfluous to the formation of the stable spherical shells; for example, in Cu, Ag and Au, the single electron which is so easily lost in chemical reactions is certainly less firmly bound than the others, and must be superfluous to the formation of a stable shell. These elements will have one free electron for every atom, and the free electrons will occupy, on the average, the positions of the chlorine ions in sodium chloride. In Mg, Zn and Cd there are presumably two free electrons per atom, with average positions the same as the fluorine atoms in CaF_2.

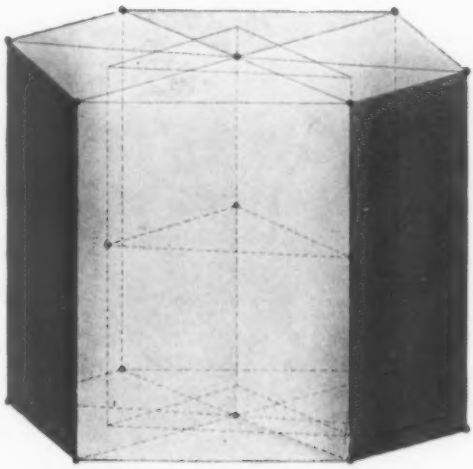
The presence of free electrons in the lattice accounts at once for the mobile cohesion and the conductivity. Whether a face-

[13] Cf. Born, *Verh. d. deut. physk. Gesell.*, **20**, 230, 1918.

centered cubic type of lattice is possible without free electrons or ions to hold it together must remain questionable until the remaining elements have been examined. Such a substance would probably be non-metallic.

There is one other element, indium, which should be classed with the cubic close-packed metals, though its structure is not face-centered cubic but face-centered tetragonal. The arrangement is the same as cubic close packing except that it is stretched six per

FIG. 11*a*.



Model of hexagonal close-packed arrangement.

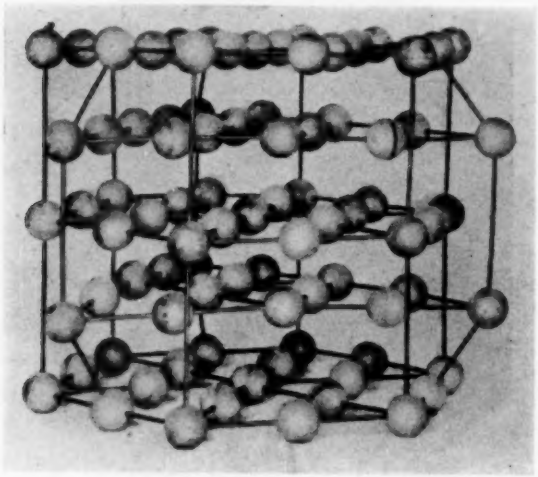
cent. in the direction of one of the cubic axes. This is exactly the arrangement that eggs would assume if packed as closely as possible. The indium atom may therefore be pictured as having a rigid outer shell of electrons in the form of an oblate spheroid, with major axis 1.06 times the minor axis.

The next most common type is the *hexagonal close-packed* arrangement. It is the second of the two alternative close-packed arrangements which equal hard spheres assume when put into a box and shaken. It is equally close-packed with the cubic close-packed arrangement, each being derivable from the other by a simple shear. This arrangement is shown in Figs. 11*a* and 11*b*. Each atom is surrounded, as in cubic close packing, by 12 nearest neighbors, all equidistant and uniformly spaced, but with slightly different arrangement, giving to the crystal an hexagonal instead

of cubic symmetry. It is an instructive pastime to study these two close-packed arrangements of spheres with a few small balls, such as are used for ball bearings.

Nine elements, all metallic, crystallize with the hexagonal close-packed arrangement. Only three of these, *viz.*, Mg, Co and Ce, have the *true* close-packed arrangement of spheres, and two, Co and Ce, appear to exist in both the cubic and hexagonal close-

FIG. 11*b*.



Model of hexagonal close-packed arrangement.

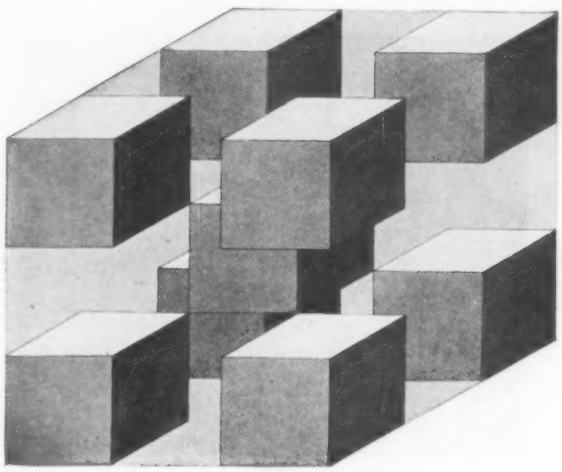
packed arrangements. It may be predicted that the passage from one of these forms to the other will not be accompanied by any measurable evolution of heat, since the potential energies of the two arrangements are identical for truly spherical atoms.

The remaining six hexagonal close-packed elements are slightly elongated or shortened in the direction of the hexagonal axis. Zinc is elongated 14 per cent., cadmium 16 per cent., while Ru, Ti, Zr and Os are *shortened* 3 per cent. These are exactly the arrangements which solid prolate and oblate spheroids would assume respectively, if packed as closely as possible, being alternative to the corresponding face-centered tetragonal arrangements. It seems very probable that the outer electron shells of

these atoms actually are spheroidal in shape as indicated by their crystal structure.

Eight elements crystallize in a *body-centered cubic* arrangement, as illustrated in Fig. 12. Each atom is surrounded by eight others, in the direction of the eight cube corners. The atoms have been represented as cubes in order to bring out this fact. The arrangement is that which would result from cubical atoms holding on to each other by their cube corners, by sharing electrons, for

FIG. 12.



Body-centered cubic arrangement.

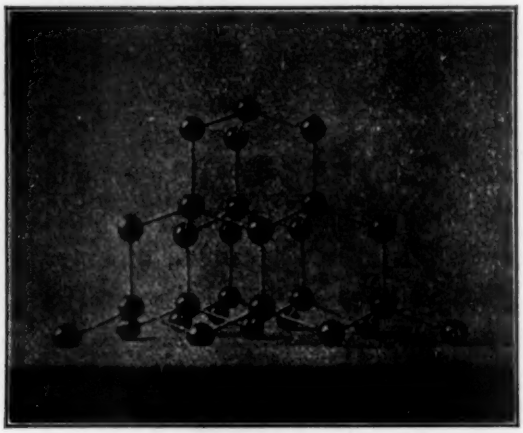
example. It might also be the result of an octahedral shape for the outer electron shell of the atoms such as might be expected if the atom shell were composed of eight electrons rotating around the eight corners of a cube, as in Landé's model of Neon.[14]

Three elements, carbon (diamond), silicon, and gray tin, crystallize in the tetrahedral arrangement, represented by Fig. 13 (taken from Bragg's model of diamond). Each atom is symmetrically surrounded by four others, and in this case there is strong chemical evidence that the atoms are really tetrahedral in shape.

[14] Landé, *Verh. D. Phys. Ges.*, **21**, 2, 1919.

Finally, there are three elements, carbon (graphite), antimony, and bismuth, whose crystalline arrangements are composed of two intermeshed rhombohedral lattices. Graphite may be described as a greatly stretched diamond structure, in which the pairs of planes perpendicular to the cube diagonal are spread apart, from 2.05 angstroms to 3.40Å, making the crystal exceedingly weak and cleavable parallel to these planes. The unit of structure of antimony and bismuth, as given by James and Tunstall [15] is represented in Fig. 15. These two elements are especially interesting

FIG. 13.



Tetrahedral or diamond arrangement.

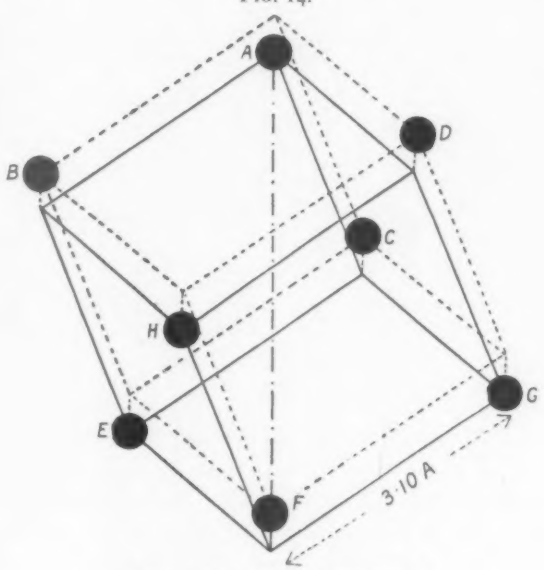
because their structure is very nearly simple cubic, each atom being surrounded by *six* nearest neighbors (as in Fig. 16, which represents the structure of rock salt). No other examples of this kind have been found among elements. In Fig. 15 the full lines represent the slightly distorted cube which is the unit of structure, its angle being changed from 90° to 92°53′ in the case of antimony; and the dotted lines the additional slight shift, in the direction of the hexagonal axis, which must be given to half of the atoms. These two elements require more study before their very unusual physical properties can be correlated with their crystal structure.

[15] James and Tunstall, *Phil. Mag.*, **40**, 233, 1920.

CRYSTAL STRUCTURE AND THE PERIODIC TABLE.

In order to show the relation of crystal structure to chemical properties of the elements, the data in Table 1 have been represented graphically on a Mendelejeff chart, in Fig. 15. This chart brings out some striking relations. *Elements in the same vertical column all have the same crystal structure.* The only exceptions are iron in group 8, which is in many ways an exceptional ele-

FIG. 14.



Arrangement of atoms in antimony.

ment; and lead and thorium in group 4, where the tetrahedral property that is so strong in the low atomic number elements (C and Si) becomes less and less pronounced with increasing atomic number,[16] and appears to be completely lost in the spherical atoms Pb and Th.

The face-centered cubic elements are found mainly in the right-hand columns of groups 1 and 8, that is in the *middle of the long periods.* The elements immediately preceding and following these middle elements, *viz.*, the left column of group 8 and right column of group 2, are hexagonal close-packed. Still lower in the

[16] Hull, *Phys. Rev.*, **18**, 88, 1921.

FIG. 15.

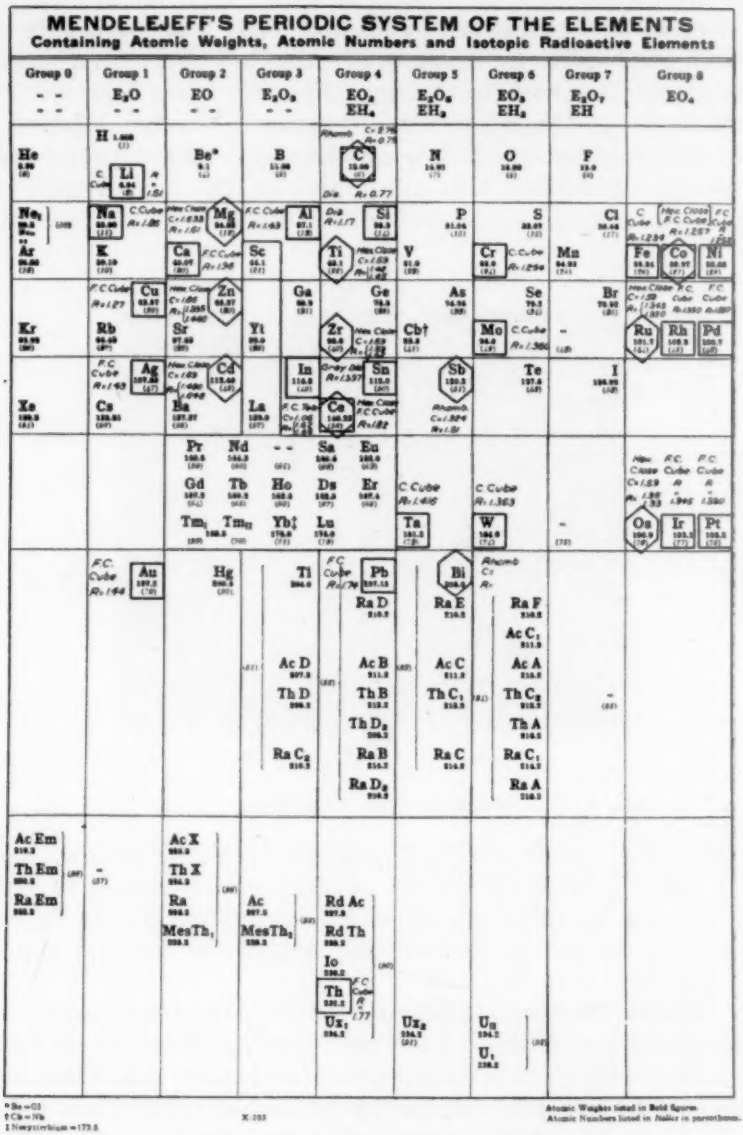
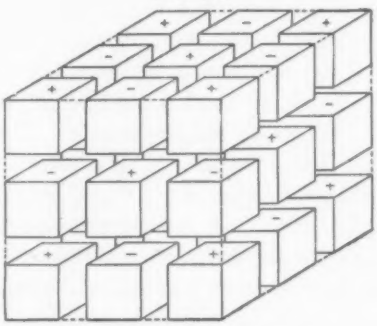


Chart showing crystal structure of elements.

long periods, in *groups 5 and 6 (left), the elements are all centered cubic.* Finally, the elements of group 4 are all tetrahedral in the right column and hexagonal close-packed in the left.

An attempt to explain these periodic crystalline properties of the elements by the models of atomic structure recently proposed by Langmuir,[17] Bohr,[18] Bury,[19] and others, would be premature. It is clear from Fig. 15, however, that *crystal structure is the same periodic function of atomic number as is chemical behavior.* The

FIG. 16.



Arrangement of ions in rock salt.

two are presumably due to a common cause, which is certainly to be found in the number and configuration of electrons in the outer shell of the atom.

Whether this common cause is the sharing or exchange of valence electrons, or the shapes of the stable shells, must be determined by further experiments. The evidence here given indicates that the loss of valence electrons, which become *free electrons*, is the primary factor in the crystallization of elements; and that the shape of the remaining shell is the secondary factor, which determines the manner in which the atoms will pack together. The general principle is that the atoms tend to pack as closely as their shape and the number of free electrons will allow.

ATOMIC DIAMETERS.

The distances between nearest atoms in Table 1 may be called the effective diameters of the atoms in the elementary state. The question naturally arises: How near are these values to the actual

[17] Langmuir, *J. Am. Chem. Soc.*, **41**, 868, 1919.
[18] Bohr, *Nature*, **107**, 104, Mar. 24, 1921.
[19] Bury, *J. Am. Chem. Soc.*, **43**, 1602, 1921.

diameters of the outer shells of electrons? Many lines of evidence conspire to indicate that they are very close.

Richards [20] has frequently called attention of the fact that the compressibilities of substances are consistent with *elastic* spherical atoms of definite size. He has been able to calculate this size in the case of the alkali and halogen atoms, [21] from the compressibility and the contraction during chemical combination. These values are given in Table 2, for comparison with those obtained by other methods.

Rankine [22] has recalculated the dimensions of these atoms from viscosity measurements, taking account of the shape of the molecules, as suggested by recent atomic structure theory. He constructs a molecule of Cl_2 by combining two argon atoms, each of diameter given by viscosity measurements, with centres 2.05A apart, as found by Bragg from X-ray crystal measurements for chlorine. The theoretical viscosity of this molecule is found to agree quantitatively with the measured viscosity of chlorine, within the limit of experimental error. The same is found to be true for the other halogens. He therefore concludes that the diameters of the halogen and alkali atoms may be taken as equal to those of the adjacent inert gases, as determined by viscosity measurements. These values are given in Table 2.

Born and Landé, in a brilliant series of mathematical investigations, have succeeded in calculating the theoretical dimensions of lattices built up of positive and negative ions, like sodium and chlorine, held together by electrostatic attraction. They find that ring atoms built on the Bohr model give lattices for the alkali halogen salts of the right dimensions, but twice as compressible as the actual salts. Cubical atoms on the other hand, give both the right dimensions and the right compressibility, and the diameters of the outer shells of electrons come out to be very nearly equal to the distance between adjacent atoms,[23] that is, the electron shells are approximately in contact in these crystals. Landé's values of atomic diameter are also given in Table 2.

W. L. Bragg [24] has made a systematic study of the distances

[20] Richards, *J. Am. Chem. Soc.*, **36**, 2417, 1914.
[21] Richards, *J. Am. Chem. Soc.*, **43**, July, 1921.
[22] Rankine, *Proc. Roy. Soc.*, Feb., 1921.
[23] Landé, *Zeit. f. Physik*, **1**, 191, 1920.
[24] W. L. Bragg, *Phil. Mag.*, **40**, 169, 1920.

between adjacent atoms in all the substances for which data have been obtained by X-ray crystal analysis, and has shown that excellent agreement with the experimental values is obtained by assuming the atoms to be spheres of definite diameter, packed together as

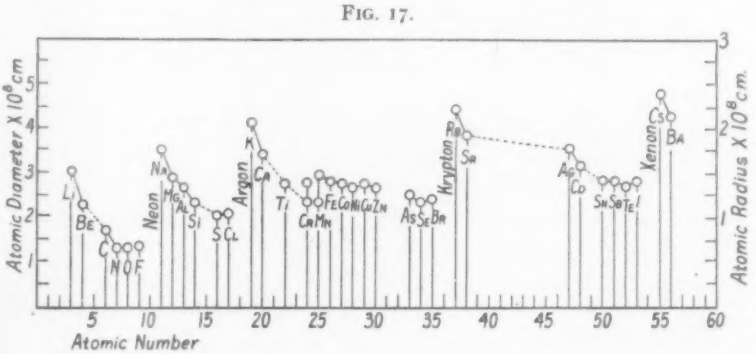
TABLE II.
Radii of Atoms.

Elements	Viscosity (Rankine)	Compressibility (Richards)	Atomic Structure (Lande)	X-ray Data Davey	X-ray Data Bragg
Fluorine	1.17			1.13	.67
Chlorine	1.43	1.4	1.6	1.56	1.05
Bromine	1.59	1.5	1.8	1.73	1.19
Iodine	1.75	1.7	2.0	1.98	1.40
Sodium	1.17	1.5	1.1	1.25	1.77
Potassium	1.43	1.7	1.45	1.56	2.07
Rubidium	1.59	1.9	1.65	1.73	2.25
Cæsium	1.75	1.9	1.60	1.98	2.37

closely as possible. Bragg's values for the alkali and halogen atoms are given in Table 2, together with a set of values recently published by W. P. Davey, which will be discussed later.

The agreement between the values in the first four columns in

FIG. 17.



W. L. Bragg's atomic diameters.

Table 2 is remarkable, when one considers the widely different methods by which they were obtained. Bragg's values, in the fifth column, should not properly be compared with the others, as they were derived for use in building up crystal models *where the negative elements share electrons with each other* and are thus

able to approach much closer, *i.e.*, have smaller apparent diameters.

The Bragg values were included in the table in order to call attention to the fact, emphasized by both Richards and Bragg, that

TABLE III.

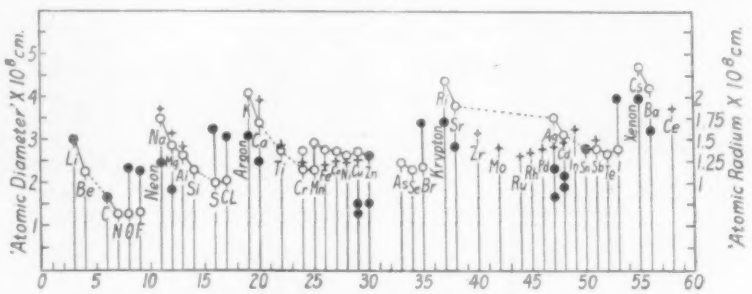
Atomic Diameters Determined from X-ray Crystal Analysis. (W. L. Bragg.)

Atomic Number	Element	Atomic Diameter in A	Atomic Radius in A
3	Lithium	3.00	1.50
4	Beryllium	2.30	1.15
6	Carbon	1.54	0.77
7	Nitrogen	1.30	0.65
8	Oxygen	1.30	0.65
9	Fluorine	1.35	0.67
11	Sodium	3.55	1.77
12	Magnesium	2.85	1.42
13	Aluminium	2.70	1.35
14	Silicon	2.35	1.17
16	Sulphur	2.05	1.02
17	Chlorine	2.10	1.05
19	Potassium	4.15	2.07
20	Calcium	3.40	1.70
22	Titanium	2.80	1.40
24	Chromium	2.80	1.40
	("electronegative")	2.35	1.17
25	Manganese	2.95	1.47
	("electronegative")	2.35	1.17
26	Iron	2.80	1.40
27	Cobalt	2.75	1.37
28	Nickel	2.70	1.35
29	Copper	2.75	1.37
30	Zinc	2.65	1.32
33	Arsenic	2.52	1.26
34	Selenium	2.35	1.17
35	Bromine	2.38	1.19
37	Rubidium	4.50	2.25
38	Strontium	3.90	1.95
47	Silver	3.55	1.77
48	Cadmium	3.20	1.60
50	Tin	2.80	1.40
51	Antimony	2.80	1.40
52	Tellurium	2.65	1.33
53	Iodine	2.80	1.40
55	Cæsium	4.75	2.37
56	Barium	4.20	2.10
81	Thallium	4.50	2.25
82	Lead	3.80	1.90
83	Bismuth	2.96	1.48

the closeness of approach of atoms depends on the force pulling them together. The apparent diameter will therefore be progressively smaller according as the atoms unite as simple elements,

univalent ions, divalent ions, trivalent ions, or covalence compounds, sharing electrons. An excellent example is calcium,[25] whose atoms have the same face-centered cubic arrangement in the metal, oxide (CaO), and fluoride (CaF_2). The oxygen and fluorine ions are able to fit in between the calcium atoms without disturbing their arrangement. Instead of forcing the Ca atoms apart, however, they draw them closer together, the distance between nearest Ca atoms in metallic calcium, CaF_2 and CaO respectively being 3.93, 3.88 and 3.42 angstroms. The singly charged fluorine ions are more effective than the free electrons in drawing the Ca atoms together, and the doubly charged oxygen ions still more effective. The difference between the apparent

FIG. 18.



Comparison of Bragg's atomic diameters (circles) with those given in Table I (crosses) and Davey's ion diameters (black dots).

diameter of sodium in the metallic state and in sodium fluoride is still more marked, though in this case the arrangement of the sodium atoms is different in the two cases.

It is probable that when the forces between atoms are better known this variation in apparent diameter can be taken account of in terms of one or more elastic constants, and a definite diameter found for each atom. For the present, however, consistent results will be obtained by using in each particular case that value of diameter which was determined from a compound of the same type as the one under investigation. This has been done by W. L. Bragg, and has proved of great service in the analysis of complex crystals. Bragg's values of atomic diameter are given in Table 3, and shown graphically in Fig. 17. They are based pri-

[25] Hull, *Phys. Rev.*, **17**, 42, 1921.

TABLE IV.

Crystal Structure of Compounds.

Compound.	Type of Lattice.	Lattice Constant [Side of Elementary Cube, Hexagon, or Rhombohedron.]	Closest Approach of Atoms.		Authority.
			Name of Atom or Ion.	Distance in Angstrom.	
LiF	Simple cubic	4.14	Li-F	2.07	Debye [20]
NH_4Cl at 20°C	Body-centered cubic	3.859	NH_4-Cl	3.342	Bragg [21]; Bartlett [22]
NH_4Cl at 250°C	Simple cubic	6.533	NH_4-Cl	3.266	Bartlett [22]
NH_4Br at 20°C	Body-centered cubic	3.988	NH_4-Br	3.453	Bartlett [22]
NH_4Br at 250°C	Simple cubic	6.90	NH_4-Br	3.45	Bartlett [22]
NH_4I at 20°C	Simple cubic	7.20	NH_4-I	3.60	Vegard [23]; Bartlett [22]; Bragg [25]; Wyckoff [26]
$NaNO_3$	Rhombohedral	6.06			
NaF	Simple cubic	4.62	Na-F	2.31	Hull [24]
NaCl	Simple cubic	5.628	Na-Cl	2.814	Bragg [25]
NaBr	Simple cubic	5.98	Na-Br	2.99	Davey [23]
NaI	Simple cubic	6.44	Na-I	3.22	Davey [23]
$MgAl_2O_4$	Diamond cubic				W. H. Bragg [25]; Nishikawa [29]
MgO	Simple cubic	4.22	Mg-O	2.11	Hull [24]
SiC	Diamond cubic (nearly)	4.356	Si-C	1.88	Burdick [31]
KF	Simple cubic	5.38	K-F	2.66	Hull [24]
KCl	Simple cubic	6.30	K-Cl	3.15	Bragg [27]
KBr	Simple cubic	6.60	K-Br	3.30	Bragg [27]
KI	Simple cubic	7.02	K-I	3.51	Davey [23]
$CaCO_3$(calcite)	Rhombohedral	6.16	Ca-C Ca-O C-O	3.04 2.30 1.21	Bragg [25]; Wyckoff [32]
CaO	Simple cubic	4.84	Ca-O	2.42	Davey [23]
CaF_2	Tetrahedral cubic	5.49	Ca-F	2.38	Bragg [25]
CaS	Simple cubic	5.64	Ca-S	2.82	Davey [24]
TiO_2 (Anatase)	Diamond tetragonal	5.27	Ti-O	1.95	Vegard [33]
$MnCO_3$	Rhombohedral	5.62	Mn-C Mn-O C-O	2.83 1.06 1.22	Wyckoff [32]
MnS_2					Bragg [25]
$FeCO_3$	Same structure and distance as $MnCO_3$				Wyckoff [32]
Fe_3O_4	Diamond cubic	8.36			Bragg [29]; Nishikawa [30]
FeS_2	Diamond cubic	5.38	Fe-S	2.25	Bragg [25]
NiO	Simple cubic	4.15	Ni-O	2.07	Davey [23]
Cu_2O	Tetrahedral cubic	4.26	Cu-O	1.84	Bragg [27]; Davey [23]
CuCl	Diamond cubic	5.36	Cu-Cl	2.32	Wyckoff [34]
CuBr	Diamond cubic	5.74	Cu-Br	2.49	Wyckoff [34]
CuI	Diamond cubic	6.07	Cu-I	2.63	Wyckoff [34]
$CuFeS_2$	Diamond cubic (nearly)	5.23			Burdick [31]
ZnO	Tetrahedral hexagonal	3.22	Zn-O	1.97	Bragg [27]
ZnS	Diamond cubic	5.41	Zn-S	2.35	Bragg [25]
RbBr	Simple cubic	6.92	RbBr	3.46	Davey [23]
RbI	Simple cubic	7.32	RbI	3.66	Davey [23]
SrF_2	Tetrahedral cubic	5.77	Sr-F	2.50	Davey [24]
Ag_2O	Tetrahedral cubic	4.70	Ag-O	2.03	Davey [24]
AgCl	Simple cubic	5.56	Ag-Cl	2.78	Wilsey [35]
AgBr	Simple cubic	5.78	Ag-Br	2.89	Wilsey [35]
AgI	Diamond cubic	6.53	Ag-I	2.83	Wilsey [35]
CdO	Simple cubic	4.61	Cd-O	2.30	Davey [23]
CdS	Tetrahedral hexagonal	4.16	Cd-S	2.54	Davey [24]
SnS	Tetrahedral hexagonal	3.60	Sn-S	2.20	Davey [24]
CsCl	Body-centered cubic	4.10	Cs-Cl	3.55	Davey [41]
CsBr	Body-centered cubic	4.33	Cs-Br	3.75	Davey [41]
CsI	Body-centered cubic	4.57	Cs-I	3.96	Davey [23]
$CsClI_2$	Rhombohedral				Wyckoff [42]
BaF_2	Tetrahedral cubic	6.20	Ba-F	2.69	Davey [24]
BaS	Simple cubic	6.40	Ba-S	3.20	Davey [24]
TlCl	Body-centered cubic	3.85	Tl-Cl	3.34	Davey [41]
PbS	Simple cubic	5.80	Pb-S	2.90	Davey [24]

marily on compounds in which the electronegative elements share electrons.

Another set of diameters, based entirely on monovalent and divalent ions, has recently been published by Davey.[26] Davey postulates the approximate equality of the K^+ and Cl^- ions in KCl, Rb^+ and Br^- ions in RbBr, and Cs^+ and I^- ions in CsI. Other monovalent ions are then found by differences. For the sake of comparison Davey's values and the values for pure elements, from Table 1, are shown on the same plot with Bragg's values in Fig. 18.

Finally, a list of the compounds that have been analyzed, arranged in order of atomic weight of the metal, is given in Table 4. The lattices referred to are the complete lattices of *ions*, counting both kinds; for example, by simple cubic lattice is meant a lattice like Fig. 16, in which half the positions are filled by positive ions and half by negative. The body-centered cubic lattice is like Fig. 12, the diamond cubic lattice like Fig. 13. The rhombohedral lattices are similar to Fig. 16, but stretched or shortened in the direction of one of the cube diagonals.

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On Phosphorescent Zinc Sulphide. R. TOMASCEK. (*Ann. d. Phys.*, No. 11, 1921.)—Much labor of investigation has been expended on the study of the phosphorescence of commercial zinc sulphide, but owing to ignorance of the exact chemical composition of the material employed all too much of this work has gone for nothing.

Chemically pure zinc sulphide was prepared with care. This showed after it had been illuminated either no phosphorescent light or so little as to be almost invisible. As the material approached chemical purity, the phosphorescent light accordingly became less and less, just as has been found to be the case with the phosphorescing compounds of the alkali earths. When a heavy metal was introduced into such a mass of zinc sulphate it became phosphorescent. For example, .000006 gram copper per gram of the sulphide produced a splendidly glowing substance. The method of crystallization of the compound seems to have no influence on the result.

The effect of the addition of small quantities not only of copper and manganese, whose efficacy in producing phosphorescence has long been recognized, but as well of Bi, Ag, Pb, Ur, Ni and Co was investigated. The preparations made with these six elements were in general not so brilliant as the copper and the manganese complexes are at ordinary temperatures, yet most of them when illuminated at the temperature of liquid air and then heated display fine and characteristic phosphorescent light. The addition of a trace of nickel caused an intense color to appear at room temperature.

With certain metals four circumstances of the admixture were examined as to their influence on the light of phosphorescence, *viz.*, the proportion of metal added, the temperature at which this trace was heated with the zinc sulphide, the duration of this heating and the flux employed.

This investigation will go far toward disentangling the twisted threads of experimental results that have so long with baffling confusion annoyed and misled in this field.

G. F. S.

FOGS AND CLOUDS.*

BY

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EVAPORATION AND PRECIPITATION.

WHERE FROM AND WHERE TO.

EVERYONE knows that rain and snow come out of the clouds, and that every cloud and fog particle is either a water droplet or an ice crystal. Naturally, therefore, one asks where all this endless supply of water comes from; endless, because year after year, century after century, and age after age, rain and snow have descended as they now descend. And where, too, does it all go, this world average of sixteen million tons a second? The answers are: It comes from the soil and its vegetation, from rivers, lakes and the oceans; and to them it returns—an endless cycle of evaporation and condensation.

> "The mist and cloud will turn to rain,
> The rain to mist and cloud again."
> —*Longfellow.*

EVAPORATION.

The first of these processes, namely, evaporation, consists in the change of water (water in this case, though many substances behave similarly) from the liquid, or even solid, state to that of an invisible gas, in which condition it becomes an important, though always relatively small, part of the air we breathe.

The rate of this evaporation depends on a number of things, the more important of which are:

a. The area of the evaporating surface. The larger the surface the more rapid the total evaporation. It is in recognition of this law that we spread out a drop or even a puddle of water to hasten its disappearance.

b. The temperature of the evaporating water. The higher

* Based on a lecture given before the Section of Physics and Chemistry of The Franklin Institute on January 5, 1922.

this temperature the more rapid the evaporation. That is why heating things hastens their drying.

c. The velocity of the wind to which the water is exposed. This explains why roads, for instance, dry so much quicker when the winds are strong than when they are light.

d. The amount of moisture already in the atmosphere. The wash on the clothes-line, as every housewife knows, dries provokingly slowly during cloudy, muggy weather.

All the other factors that affect the rate of evaporation, such as density of the air, saltiness of the water, *et cetera*, generally are small in comparison with the above, and need not here be considered since it is only intended to make perfectly clear, through our everyday experiences, the wide occurrence and great importance of evaporation.

SATURATION.

Although evaporation, as just stated, is so very general there are conditions under which things will not dry, nor bodies of water any longer decrease. Thus even a rather small amount of water in a tightly closed bottle, or other impervious vessel, remains there indefinitely. The space above the water becomes saturated, we say, by which we mean that it gets so charged with water vapor that, under the existing conditions, it can contain no more. At this stage the net evaporation is zero. That is, the amount of the invisible water vapor that now goes back, or condenses, into the liquid stage is exactly equal to that which, in the same time, leaves the liquid surface and becomes invisible vapor. In other words, at this stage, however rapid the interchange between liquid and vapor, the amount of each remains constant.

Numerous careful experiments have determined very closely the exact weight of water vapor per cubic foot, say, when the space in question is saturated at any given temperature, from the boiling point to far below that of freezing. And these experiments show two facts of paramount importance in the formation and dissipation of clouds, namely:

1. The amount of moisture necessary to produce saturation increases rapidly with increase of temperature.

2. The amount of water vapor essential to saturation is not appreciably affected by the presence or absence of the other gases of the normal atmosphere.

It is true that even in technical language we often say that the *air* contains such or such an amount of moisture, as though the presence of the air was essential to the existence of the vapor, or as though the air acted somehow like a sponge in taking up water. But, as explained, this idea is wholly wrong. The only appreciable effect of the presence of the other gases of the atmosphere on the moisture is that of slowing the rate of its spread or diffusion. Temperature and temperature alone, to within a negligible amount, determines the quantity of vapor per any given volume necessary to produce saturation, or, of course, any definite percentage or fraction of saturation.

CONDENSATION.

The percentage of saturation produced by a given amount of water vapor may, therefore, as is obvious from the above discussion, be varied by altering the volume it occupies or its temperature, or both; and as rapidly as saturation tends to be exceeded moisture condenses out onto any water surface or solid that may be present. Thus, the deposition of dew, the formation of hoar-frost, and the sweating of ice pitchers, all are examples of condensation owing to passing the saturation point, or dew-point, as it commonly is called. In these cases just mentioned the temperature of the water vapor, and, of course, of the other constituents of the atmosphere, which, however, play no part in the condensation, is lowered through contact with cold objects, and the volume of this vapor as well as that of the accompanying chilled gases, decreased—decreased because in the open air the pressure remains constant, or nearly so, whatever the degree of cooling.

Similarly, whenever the temperature of the open air passes below the dew-point condensation occurs in the form of innumerable water droplets or tiny ice crystals throughout the chilled volume, and thereby produces a fog or a cloud, as determined by location—a fog if on the surface, a cloud if only in mid-air.

The natural processes by which a given body of the atmosphere may be sufficiently cooled to lose a portion of its water vapor by condensation are: (1) Contact with objects colder than itself; (2) mixing with colder air; (3) radiation; (4) expansion.

Condensation as a result of contact cooling is well illustrated, as already explained, by the deposition of dew—the bedewed

objects having been cooled by radiation; by the formation of hoar-frost, which occurs under the same conditions, except at a lower temperature, as does dew; and by the sweating, during warm humid weather, of all cold objects. It is further illustrated by the formation of fog, generally light, when relatively warm humid air drifts over a snow bank or other cold surface.

The second of the above processes of inducing condensation, that is, the mixing of masses of humid air of different temperatures, is not very effective. Indeed an accurate calculation, based on the temperature and volume changes and other factors of the problem, shows that while a fog or cloud may be obtained by this process no appreciable amount of rain or snow is likely to result. Layer or stratus clouds at the boundary between relatively warm air above and cold beneath, a phenomenon of occasional occurrence, are at least partially due to mixing, as are also the fogs that so frequently occur over adjacent warm and cold ocean currents.

The third process by which air loses heat, namely, by radiation, probably is of little importance in the production of clouds since the most chilled portions of free air sink to lower levels and thereby become even warmer and drier than they were at first. Near the surface, however, where descent and the consequent dynamical warming, as it is called, are impossible, radiation often is very effective in the production of fog.

The last of the cooling processes mentioned above, that is, expansion, is exceedingly effective, and to it is due the great bulk of cloud formation. Now, expansion of the air may be produced either by heating it or by reducing the pressure to which it is subjected. It is the latter process, obviously, and not the former, even though heating generally is the initial cause, that produces the cooling of free air and the formation of cloud. To make these points clear, consider the results when a given mass of humid air is heated, as it may be, over a region warmed by sunshine or otherwise. With increase of temperature it expands and thereby becomes lighter, volume for volume, than the surrounding cooler air. The surrounding denser air then underruns the lighter and lifts it up to higher levels just as hot air is driven up a chimney. As the warmed air is thus forced up (rises, as we generally say) the pressure to which it is subjected obviously decreases in proportion to the weight of the air left below. It therefore gradually expands as it rises and thereby does work, and since the only

energy available for this work is the heat of the ascending air it follows that as its height increases its temperature must correspondingly decrease. As a matter of fact, for air of average humidity, the rate of this decrease is approximately 1° F. per 187 feet increase of elevation up to the base of the cloud, if there be one, in the rising air, and then much less through the cloud. In any event the ascending air attains equilibrium only when it has cooled by expansion to the temperature of the air that finally surrounds it. Hence when it comes to rest it is colder, often much colder, than it was before it was heated.

Of course the expansion of the rising air correspondingly increases the vapor capacity, but it is easy to show, both theoretically and experimentally, that this increase of vapor capacity by volume expansion is small in comparison with its simultaneous decrease through the lowering of the temperature, and that convectional expansion therefore, whether incident to the blowing of wind up and over mountains, or to local heating, is a most effective means of inducing condensation and the formation of clouds.

CONDENSATION NUCLEI.

Whenever ordinary air, kept humid by the presence of water, is suddenly expanded in a closed vessel, it instantly becomes filled throughout with a miniature cloud, precisely as occurs on an incomparably larger scale in nature. Subsequent expansions of the same air, otherwise undisturbed, induce less and less cloud and presently none at all. If filtered air, that is, air drawn through several inches of cotton wool, or other substances of similar texture, is used, condensation by moderate expansion is impossible from the first. The admission, however, of a little smoke restores to the exhausted air, and endows the filtered air with, full powers of condensation. There are, therefore, condensation nuclei in the atmosphere—hundreds and often thousands of them per cubic inch—which can be filtered out; and microscopic examination shows that they consist essentially of dust particles. Hence, dust, moisture and some cooling process are the three essential factors in all natural fog and cloud formation.

It is true that a few substances other than dust, such as the oxides of nitrogen, act as condensation nuclei, but they seem generally to be negligible in quantity. Furthermore, condensation can be obtained in air wholly free from any such nuclei provided it

is ionized and forced to at least a fourfold supersaturation, a degree of humidity that probably never occurs in nature. Indeed under very great supersaturation, eight- or ninefold, condensation occurs even in perfectly clean non-ionized air. But this, too, is only a laboratory experiment, and not a process by which clouds are formed in nature.

FOGS.

DISTINCTION BETWEEN FOG AND CLOUD.

As already explained, whenever the air is cooled, by any means whatever, below its dew-point, a portion of the water vapor present separates out on such dust particles or other condensation nuclei as may happen to be present. If this process occurs only at a considerable distance above the surface of the earth, leaving the lower air clear, the result is some form of cloud. If, on the other hand, it extends quite to, or occurs at, the surface of the earth it is then called a fog no matter how shallow nor how deep it may be. The distinction, therefore, between fog and cloud is that of position. Fog is a cloud on the earth; cloud, a fog in the sky.

In some cases the only basis of distinction between fog and cloud is that of viewpoint. For example, the mist that sometimes covers only the crest of a mountain generally is called fog by those actually in it, and cloud, at the same time, by those in the valley below.

WHERE AND HOW FORMED.

Fogs are likely to form along rivers and large creeks and in the mountain valleys of all but arid regions in the latter part of any still cloudless night of summer or autumn. During these seasons the streams and the humid soil are warm, especially when exposed to sunshine, and hence evaporate much moisture into the lower atmosphere, where, in great measure, it remains when there are no winds to blow it away.

Throughout the night, however, the surface of the soil and the adjacent humid air, by virtue of its humidity, lose heat rapidly by radiation to the colder atmosphere above and to the sky, or empty space, beyond. This loss of heat by radiation is no greater, of course, by night than in the daytime, but when there is no sunshine to make good such loss, or do better—as generally is the case through the forenoon—the inevitable consequence is a lowering of

the temperature. Hence, during calm, clear nights the temperature of the humid surface air often falls below the dew-point and a fog of corresponding depth and density is formed.

If the sky is overcast there commonly is enough radiation from the clouds back to the earth, especially if they happen to be low (hence warm), to prevent the cooling of the surface air to the dew-point and the consequent formation of fog. Neither does fog form when there is considerable wind, partly because the more humid lower air is then mixed with the drier upper air and the surface dew-point thereby lowered, and partly because this mixing prevents much fall in the surface temperature by distributing the loss of heat through a relatively large amount of air instead of leaving it confined essentially to that near the ground. Hence fogs of the kind under consideration—radiation fogs, summer fogs, land fogs, valley fogs—seldom occur either when the sky is cloudy or the night windy.

Another source of numerous fogs is the drifting of relatively warm humid air over places much colder, such as the drifting of on-shore winds over snow-banks. In this way the humid air frequently is cooled below its dew-point and fog—"winter fog" or "sea fog"—produced. Likewise, heavy fogs often are formed when the wind is from warm to cold water—from the Gulf Stream to the Labrador Current, for instance.

Fogs also frequently occur when cold air slowly flows in over warm water. This explains the "frost smokes" of polar seas, and the "steaming" of rivers and lakes on cold frosty mornings. In these cases the relatively warm water goes on evaporating into the cold air even after it becomes saturated and thereby produces a water droplet or a minute ice crystal about every one of the myriad millions of nuclei present. If, however, the cold air comes in with a rush, that is, if it enters as a strong wind, no fog is produced, simply because the vapor is distributed by the accompanying turbulence through too large a volume to produce saturation.

KINDS.

In respect to the ways in which they are formed, fogs may be divided into two classes:

1. *Radiation fog* (Fig. 66, *Physics of the Air*[1]), due to the cooling of the lower air below the dew-point, partly by its own

[1] Book published by The Franklin Institute, 1920.

radiation and partly by contact with the surface which itself had cooled by radiation. This type of fog is common, as already

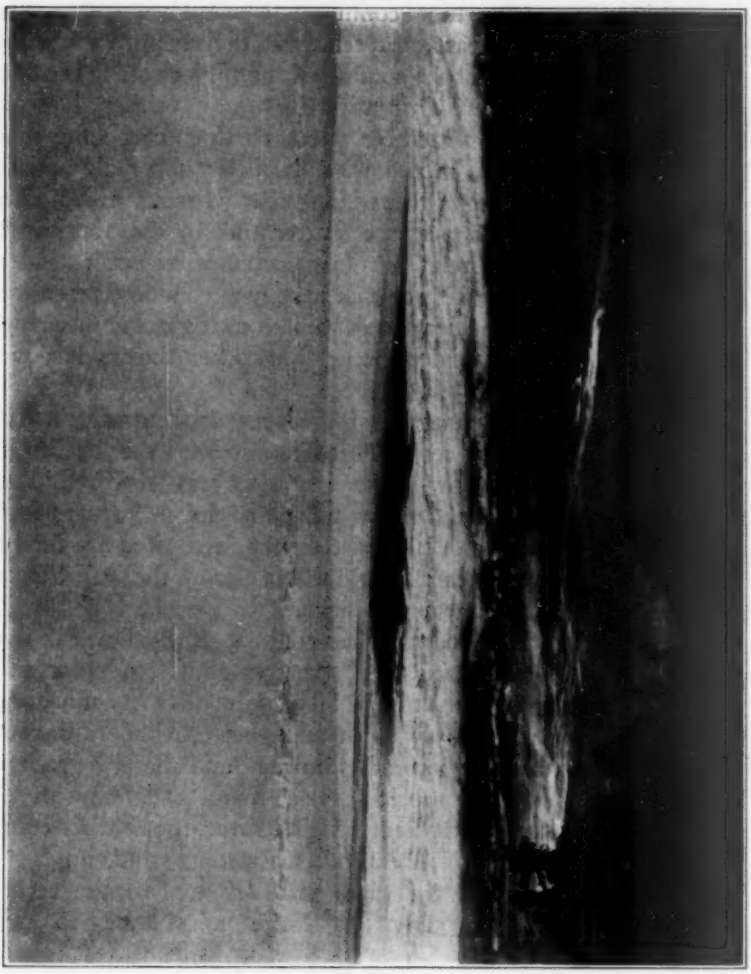

FIG. 1.

Advection fog, seen from Mount Wilson, Cal. (F. Ellerman, photo.)

explained, along streams and in valleys where, through the summer and autumn, it is apt to occur on any calm, clear night.

2. *Advection fog* (Figs. 1, 2), produced by the advection, or horizontal movement of air from one place to another, such as the drifting of relatively mild air from the ocean inland over snow-

banks, or from a warm current to a cold one; and the flow of frosty air over open water. Furthermore, any fog, when shifted to a new position may then be called advection fog. Usually, too, the

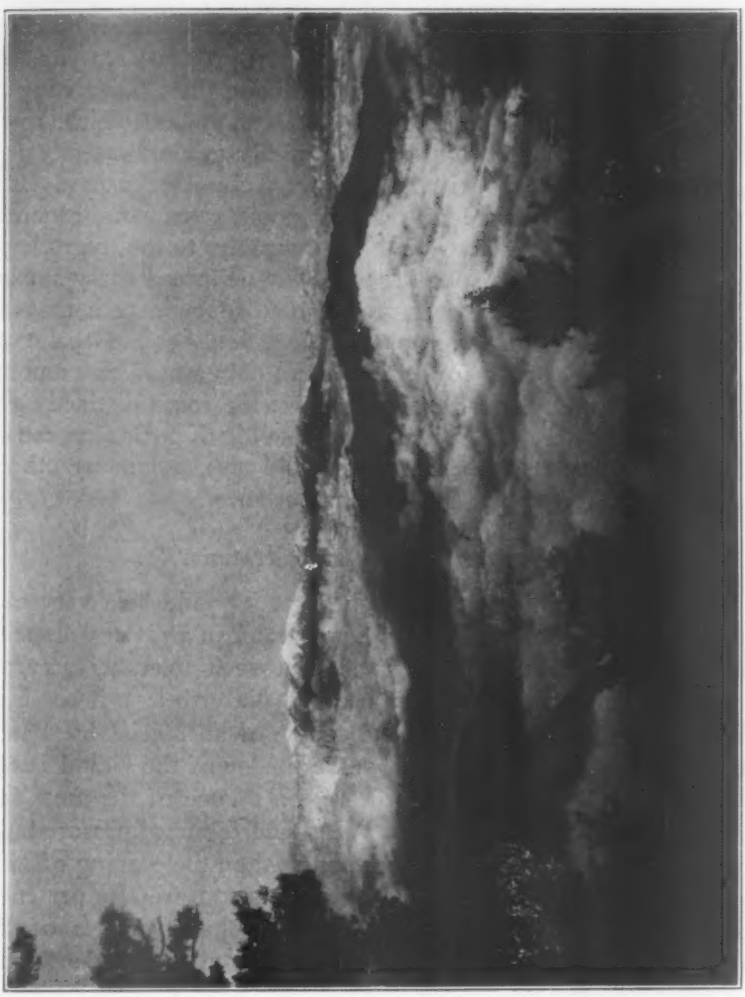

FIG. 2.

Advection fog, seen from Mount Wilson, Cal. (F. Ellerman, photo.)

shifted fog, like that so common on many leeward coasts, is advective also in origin.

There also are several other classifications of fogs, less scientific perhaps, but often very convenient. Thus we speak of

dry fog, meaning a fog which, because of the small amount of water content, does not wet our clothing—evaporates as fast as caught up—or else meaning, as we often do, a haze caused by a forest fire, dust storm, or volcanic explosion; *wet fog*, meaning one containing so much water that, like a Scotch mist, it makes at least the surface of one's clothing distinctly damp; *sea fog*, fog originating on the ocean, whether remaining there or drifting on shore; *land fog*, one occurring in the country and which, as its nuclei are but slightly hygroscopic, quickly evaporates; *city fog*, one occurring over a city, especially a city that uses a large amount of soft coal and has but few smoke consumers, generally slow to evaporate, owing jointly, presumably, to the hygroscopic nature of the nuclei and to the oil in the unburned sooty smoke; *black fog*, one containing a great amount of soot, such as occasionally forms over large, smoky cities; *pea-soup fog*, a local name given to those London fogs that contain only a moderate amount of smoke particles—just enough to give the fog a distinctly yellowish cast; *ice fog*, or "frost smoke," the fog of polar seas, caused by the drifting over them of very cold air; and many others, mostly of less interest and of small importance.

QUANTITY OF WATER CONTAINED.

It might seem, on first thought, that it would be a very easy thing to measure the amount of liquid water in a given volume of fog, but this amount is so small that even tolerably accurate measurements of it require much care. Nevertheless, it has been reliably measured. Thus, in the course of an official Ice Patrol cruise in the *Seneca* about the southern edge of the Grand Banks of Newfoundland, that is, in the region of one of the most frequented of the steamer lanes, Wells and Thuras measured the water content of a dense fog that occurred on the evening of May 9, 1915. In this fog there were about 20,000 droplets per cubic inch. In their report they say: "To gain some idea of the order of magnitude of the quantities involved in this dense fog, assume that one can not see beyond 100 feet. A block of fog 3 feet wide, 6 feet high and 100 feet long contains less than one-seventh of a glass of liquid water. This water is distributed among 60 billion drops."

Barely one good swallow!

SIZE AND NUMBER OF PARTICLES.

The size of fog particles is easily and accurately determined by looking through the fog at a point (pin-hole) source of bright light and noting the difference in direction toward centre and circumference of any definite one of the rings of colored light seen around this source—rings of precisely the same nature as the coronæ produced by thin clouds around the sun and moon. This angular size, or difference in direction between centre and circumference of any one of these rings, increases as the diameter of the fog particles decreases, and in such known and definite manner that when either is given the other can at once be accurately calculated.

If, then, we know the size of the fog particle and if, in addition, we know the amount of liquid water in a given volume of fog, which, as explained above, can be measured, it obviously is only a matter of easy arithmetic to find the number of such particles per cubic inch, say, or any other given volume.

The numbers, however, so obtained are surprising. Everyone knows, of course, that a fog droplet is small, but not many, perhaps, realize that 2500 of them, of the average size, placed side by side in a single row would extend only one inch, or, in other words, that it would take half an hour to count a string of them an inch long!

Nor is the number of fog particles in a definite volume any less amazing. It is but a light fog that has only 1000 droplets per cubic inch; a heavy fog has around 20,000. Indeed, vastly greater numbers have often been found, even up to nearly a million per cubic inch.

But these droplets, as explained, are so excessively minute that the very maximum density of a million per cubic inch would still leave the empty space 4000 times greater than the volume actually occupied by all the liquid present.

IMPRESSIONS.

If one would thrill his soul with beauty let him, on a brilliant, moonlit night, view from the mountain's crest a far flung fog over all the piedmont region beyond, with foothills and knolls rising here and there as so many enchanted islands in an enchanted sea. Let him, as the dawn breaks clear, gaze from a mountain top on an incipient, fibrous fog, covering a neighboring valley with a fabric more gauzy and delicate than ever Arachne spun. Let him

stand on the topmost peak of rugged Tamalpais and watch in wonder the mighty fog billows crowd through the Golden Gate, break over the barrier mountain crests, and rush down their sides in an all engulfing flood. Let him view from afar the snow-crowned crest of incomparable Fuji, floating without visible support, in a clean, clear sky while all its base and the region around is lost in deep fog and delicate mist.

These are but some, and typical, of the most beautiful and fascinating of fog effects; so impressive, indeed, that we could not forget them if we would, and so charming that certainly we would not forget them if we could.

But the impressions produced by fog are not always so charming and entrancing. If one would go quite to the opposite extreme and experience its terrors let him get lost in London's darkest and densest fog. Let him be alone at night in an unfamiliar forest and have settle down upon him so thick a fog that literally he can not see his hand before him. Let him, on the ocean in the dead of night, between the shrieks of his own ship's siren hear from somewhere, just somewhere, within the encircling gloom, the same dread warning. Let him, when flying over strange territory, be forced to land in a deep, dense fog!

All these, and many others, are horrors one longs to forget, but can not.

And so it is that, from extreme to extreme, from fascination to fear, from delights we fondly cherish to dreads we would fain forget, fog in all its moods and circumstances plays compellingly upon the whole gamut of human emotions.

CLOUD FORMS.

It is passing strange that the ancient Arabs, Greeks and others should have given a name to every portion of the heavens, and to numerous individual stars—names still in current use throughout the civilized world—and yet have failed to name any one of the many kinds of clouds that are even more conspicuous in the sky than the stars themselves or their constellations. Perhaps giving them names long seemed both useless and impracticable owing to their infinite variety and ceaseless changes, for indeed, as Shakespeare puts it:

Sometimes we see a cloud that's dragonish,
A vapour sometimes like a bear or lion,
A towered citadel, a pendent rock,
A forked mountain, a blue promontory
With trees upon't that nod unto the world
And mock our eyes with air.
That which is now a horse, even with a thought,
The rack dislimns and makes it indistinct
As water is in water.

But whatever the cause, there was not, down the ages, until the very modern year 1801, any attempt whatever to classify the clouds, although from the beginning everybody everywhere talked about the weather and many wrote about it. This first attempt, made in 1801, as just stated, was by the French naturalist, Lamarck. It received little attention, however, and no general acceptance; owing in part, presumably, to the fact that it was expressed in the words and phrases of a distinctly local or national language unfamiliar to the world at large.

But the time for a practical classification of the clouds was ripe. The need for it was felt by the large number of educated and cultured people who were then taking an active and inquisitive interest in the weather and its ways. Hence in a little while another classification was proposed, this time, 1803, by the Englishman, Luke Howard. Like that of Lamarck's it too was based on the *appearance* of the clouds, but the names, instead of being only locally understood, were all in tolerably familiar Latin —the Esperanto of the day. At any rate, whether this universal language had much to do with it or not, Howard's classification soon became well known and extensively used; so much so indeed that all subsequent practical classifications have been but extensions of this original one published in 1803, with the addition, perhaps, of a few unusual and, commonly, unimportant types, some of which Howard probably never saw.

To obtain uniformity in the cloud reports of professional meteorologists, and of all others who wished to be clearly understood, the International Meteorological Committee published in 1910, with illustrations, the following definitions and descriptions of cloud forms. The enclosed letters next after each type name are its customary abbreviation. The illustrations are new (the original ones are not available) but quite as good and typical, it is hoped, as those selected by the committee.

The wording here followed of these international definitions and descriptions is not exactly that of the original publication, but that given in the second edition of "Cloud Forms," 1921, by the British Meteorological Office.

This latest classification of the clouds, a modification and extension of Howard's, is also, like it, based on mere *appearance* and not on anything really fundamental, such as cause or mode of formation. But however superficial such a classification may be it nevertheless is the best, perhaps, that can be made, and altogether the most practical. For instance, the mode of origin is not a practical basis for cloud classification, however desirable, because several types of cloud are formed in different ways and frequently one cannot be certain just what the actual way really was.

The supplementary remarks, after each of the following quoted definitions and descriptions, while intrusive in position, may, it is hoped, be of some service to those who are not yet cloud experts.

(To be continued)

Lost Lake in Nevada. (*U. S. Geological Survey Press Bulletin No. 481.*)—During comparatively recent geologic time a great lake flooded a number of the valleys in northwestern Nevada. This lake has now almost completely disappeared, but geologists have named it, in its entirety, Lake Lahontan, in honor of Baron La Hontan, one of the early explorers of the headwaters of the Mississippi. At the time of its greatest expansion, according to the Geological Survey, this ancient lake covered 8400 square miles. The deepest part of Lake Lahontan, which was 880 feet deep, was the site of the present Pyramid Lake, one of its remnants, so that its surface stood about 500 feet above the surface of Pyramid Lake. The ancient lake had no outlet except the one that led straight up, its waters being dissipated entirely by evaporation.

A large area a few miles north of Winnemucca, Nevada, is covered with sand dunes that were formed since Lake Lahontan disappeared. These dunes are fully 75 feet thick, and their steeper slopes are on the east side, indicating that the whole vast field of sand is slowly traveling eastward. The march of this sand is irresistible, and its progress has necessitated a number of changes in the roads in the southern part of Little Humboldt Valley during recent years. In some places in this region the telegraph poles have been buried so deep that they have had to be spliced in order to keep the wires above the crests of the sand dunes. The sand is of a light creamy-yellow color and forms beautifully curved ridges and waves that are covered with an artistic fretwork of wind ripples.

THE EFFECT OF THE FORM AND DIMENSIONS OF THE SAMPLE UPON THE ACCURACY OF X-RAY CRYSTAL ANALYSIS BY THE POWDER METHOD.*

BY

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AN X-ray crystal analysis of certain alloys by the powder method [1] has shown that errors due to the finite dimensions of the samples employed become appreciable when maximum accuracy is attempted. Since the effect of varying the proportion of the metals forming an alloy, or of varying its properties by any other means, is usually to change slightly the dimensions of the crystal lattice, without changing its kind, the estimation of the magnitude of such errors, and efforts to reduce them, seemed worth while.

The apparatus available was designed and constructed by the staff of the Research Laboratory of the General Electric Company, and permits simultaneous analysis of as many as fifteen samples. The spatial relations of the parts essential for the analysis of one sample are indicated in Fig. 1, which is a projection on the (vertical) plane through the centre, M, of the molybdenum target from which the X-rays diverge, the centre, N, of the (horizontal) cylindrical sample, and the centre-line, ST, of the photographic film which is bent over a cylindrical frame coaxical with the sample. The diameter of the sample and the thickness of the cylindrical tube necessary for non-coherent powders or materials which are modified by exposure to the atmosphere, have, for convenience in reference, been enormously exaggerated. Points in Fig. 1 which are projections of points lying outside the plane of projection are primed. When attention is to be called to the position of these points in space the primes will be suppressed.

The fundamental equation of the method is

$$n\lambda = 2d \sin \theta$$

* Communicated by Col. John J. Carty, D. Eng., Associate Editor.

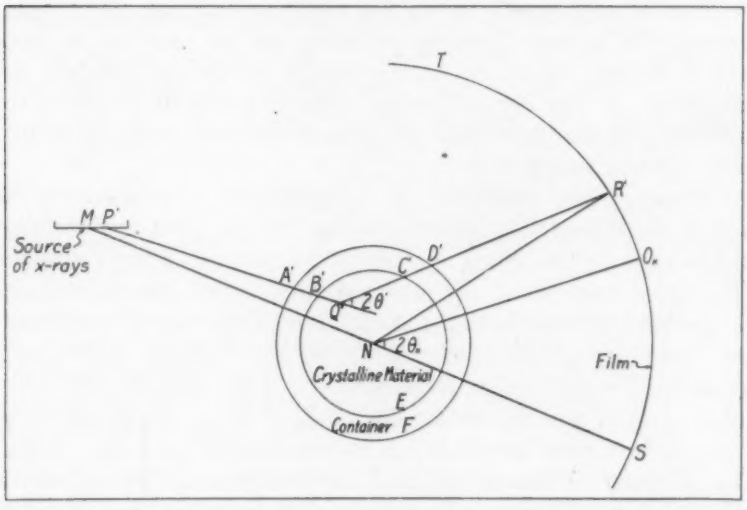
[1] For a complete description of the method see papers by A. W. Hull, *Phys. Rev.*, (2), 9, 84-87, 1917; 10, 661-696, 1917.

wherein λ is the wave-length of the X-rays, n is an integer termed the "order of reflection," θ is half of the observed deviation of the rays, and d is the perpendicular distance between the consecutive planes in the crystal from which reflection takes place. The radiation is filtered so that λ can for a first approximation be regarded as a constant. On this assumption only a limited number of values of d and n which satisfy the condition

$$\frac{d}{n} < \frac{\lambda}{2}$$

can give real reflections. Let the admissible values of $\frac{d}{n}$ be desig-

FIG. 1.



nated $d_1, d_2, d_3, \ldots d_k \ldots d_m$, in order of decreasing magnitude, and the corresponding values of θ be designated $\theta_1, \theta_2, \theta_3, \ldots \theta_k, \ldots \theta_m$, in order of ascending magnitude. The data will furnish some, rarely all, of the possible values of θ_k, and the corresponding values of d_k determine the kind and dimensions of the crystal space lattice.

The accurate determination of θ_k, or more strictly of $2\theta_k$, the angle of deviation, is the problem to be solved. The measurement is reducible to that of a single length, SO_k, on the centre-line of the film after it has been exposed, developed, fixed, washed and dried. All the other lengths involved in the calculation of $2\theta_k$ are constants characteristic of the film-box and sample-holder. If

the film guides are not true circles centered on the axis of the sample, the length of SO_k as measured must be suitably corrected, the correction being a function of SO_k alone, before θ_k and d_k are computed.

The filters, which render the X-rays monochromatic to an extent sufficient for photography, are placed in the incident beam close to the X-ray tube, and in the diffracted beams close to the film. They are not indicated in Fig. 1. The effect of heterogeneity in the radiation reaching the film will be discussed later; meanwhile it will be assumed that only a single wave-length is present.

The focal spot on the target is of finite dimensions, but for the first approximation it can be assumed that all the X-rays diverge from the centre of the focal spot. The slits which limit the incident beam are of such dimensions and so placed that at the sample the cross-section of the beam which is of full intensity is a rectangle 1.8 cm. horizontally by 0.15 cm. vertically. It will be assumed that the X-ray tube, slit system, and sample-holder are correctly arranged so that the central portion of the sample lies entirely within this rectangle.

The film [2] is 40.4 cm. by 4.7 cm. and as limited by guides, screens and filters the undeviated X-rays form upon it a rectangular spot about 4 cm. by 0.5 cm., 8 cm. from the lower end. The deviated rays form a strip of diffuse blackening about 3 cm. wide, beginning about 2 cm. above the undeviated spot and extending with diminishing intensity for about 25 cm. along the centre-line of the film. This strip, due to scattering by amorphous material, stray and unfiltered radiation, is crossed by darker bands which cut the centre-line of the film very close to the points O_1, O_2, ... O_k, ... O_m, whose positions are desired. The sample casts its shadow on the undeviated spot as a lighter band, the centre-line of which cuts the centre-line of the film at the point S.

The shadow of the sample must be clear enough so that the point S can be located at least as accurately as the points O_k. This requires that the absorption in the sample be appreciable, since any attempt to locate S by an auxiliary exposure using an opaque object in place of the sample largely increases the accidental errors affecting the measurement of SO_k.

The blackening of the film at any point R, in excess of that due to the diffuse radiation mentioned above, is due to diffraction from

[2] Eastman Portrait Film 17/8" x 16".

every crystal in the sample which can deviate rays through any angle so as to fall at the point R. The intensity of X-radiation of wave-length λ incident from a point P of the source upon an element, at Q, of a properly exposed sample, depends only upon the intensity on a plane perpendicular to PQ at unit distance from P, upon the length of PQ, and upon the absorption in intervening matter. The absorption in the wall of the X-ray tube, in the filter, and in the air is the same for all points of the source and of the sample. The absorption in the sample itself and its container depends principally upon the position of Q and only very slightly upon the position of P. If the arrangement of crystals in the sample is truly chaotic, as desired, the same fraction of the total mass in every element of volume is in position to deviate some incident radiation through the angle 2θ where θ has any assigned value. Of course, if θ is not nearly equal to θ_k, one of the values corresponding to the crystals forming the sample, the fraction so deviated will be negligible, but this can more conveniently be taken account of at a later stage in the analysis, so that at present θ will be regarded as unrestricted.

The distribution of the radiation deviated through 2θ in the element of volume at Q is symmetrical about PQ as an axis, the deviated rays thus forming a thin conical shell with apex at Q. The point R is a point on the intersection of this cone with the film. The component normal to the film at R of this deviated radiation from Q is proportional to the whole intensity deviated through 2θ at Q and depends also upon θ, upon the length QR, upon the absorption in matter between Q and R, and upon the angle QR makes with the normal to the film at R. The absorption in the sample itself and in its container is again seen to be the only absorption which varies much with the choice of Q.

Holding the point R fixed and permitting P and Q to take all possible positions consistent with the boundary conditions at the source and sample we can now write down the expression for the total intensity of radiation received normally at R,

$$I_R = A_R + \int_P ds \int_Q u(P,Q)\, w(\theta_{P,Q}) \left\{ \frac{I}{PQ^2} \cdot \frac{I}{QR^2} \cos(QR \cdot NR') \right.$$
$$\left. e^{-\mu_E (BQ+QC) - \mu_F (AB+CD)} \right\} dv$$

wherein A_R is the intensity of diffuse radiation. The volume

integral is to be taken throughout the sample, the surface integral is to be extended over the source. The absorption has been assumed to be exponential, μ_E and μ_F, referring to the sample and its container, respectively. The function $u(P,Q)$ contains all the factors dependent upon the position of P and the direction of PQ with respect to the axis of the X-ray tube. The function $w(\theta_{P,Q})$ includes all the factors which depend on the position of Q only through the corresponding value of θ. Its value has maxima at or near[3] $\theta = \theta_k$, and is practically zero elsewhere.

The resolution of the bands in the photograph is complete at R if only one maximum in w is included within the range in θ permitted by the possible positions of P and Q. This cannot, unfortunately, always be the case unless the unit of crystal structure is small, for the dimensions of the sample, and particularly its length, cannot be reduced without great loss of intensity, and adjacent values of θ_k often lie very close together.

The relative dimensions of the apparatus are such that several approximations can be introduced without serious error, provided R is kept near O_k which includes all the interesting portion of the photograph. We may put

$$u(P,Q) = u(P,N) \ ,$$

$$\int_P u(P,N)\, ds = G \ , \quad \text{a constant}$$

$$\frac{1}{PQ^2} \cdot \frac{1}{QR^2} = \frac{1}{MN^2} \cdot \frac{1}{NO_k^2} = C_k, \quad \text{a constant}$$

$$\cos(QR \cdot NR') = 1 \ ,$$

$$\frac{A_R}{I_R} = 0 \ ,$$

$$B'Q' = BQ \ , \quad Q'C' = QC \ , \quad A'B' = AB \ , \quad C'D' = CD \ ,$$

$$w(\theta_{P,Q}) = w_k \ \text{ for } \theta_k + \epsilon > \theta > \theta_k - \epsilon,$$

$$w(\theta_{P,Q}) = 0 \ \text{ for } \theta > \theta_k + \epsilon \text{ and } \theta_k - \epsilon > \theta,$$

leaving

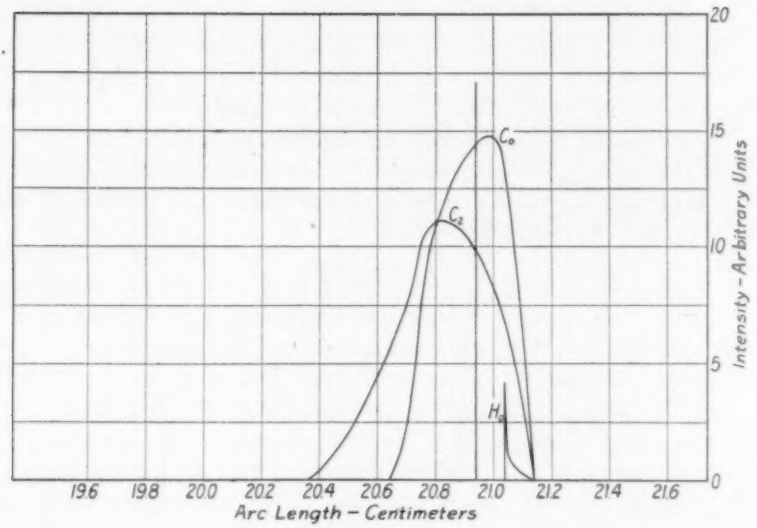
$$I_R = G\, C_k\, w_k \int_{\theta_k - \epsilon}^{\theta_k + \epsilon} \left\{ e^{-\mu_E (B'Q' + Q'C') - \mu_F (A'B' + C'D')} \right\} d\nu$$

[3] Wilson, H. A., *Phys. Rev.*, (2), **18**, 396-401, November, 1921.

wherein the limits for the integration include all the points, Q, of the sample from which a sensible intensity is deviable to R by the given crystalline material. In the above simplified expressions ϵ is a small angle, 2ϵ being the width of the rectangle which best fits the peak in the w, θ, curve, and w_k being its altitude, so that

$$2\, w_k\, \epsilon = \int_{\theta_k - \delta}^{\theta_k + \delta} w(\theta)\, d\theta$$

FIG. 2.



wherein δ is any angle large compared with ϵ but small compared with $\theta_{k+1} - \theta_k$ and $\theta_k - \theta_{k-1}$.

In the case to be treated herein the value of ϵ is entirely negligible with respect to the angles subtended by the bands on the photograph, so the volume integration can be replaced by integration over the surface produced by rotating the arc PQR about its chord PR. The last equation takes the form

$$I_R = G\, C_k\, W_k \int_{\theta_k} \left\{ e^{-\mu_E (B'Q' + Q'C')} - \mu_F (A'B' + C'D') \right\} ds$$

Even with these simplifications a formal solution has not been obtained, but enough special cases have been approximately computed to indicate the type of variation to be expected if the blackening of the photograph is approximately proportional to I_R, as it is in the case of under-exposure usually occurring. The remaining figures show the results of computation in several cases, the curves being lettered to correspond to the nomenclature given in the table below. The subscript of the letter placed close to each curve gives the distance in centimeters from the centre-line of the film to the line for which the intensity is plotted (*e.g.*, A_0 refers to the centre-line, A_2 to a parallel line two centimeters away). A vertical line on each figure represents the point to which measurement should be made, the point O_k in the preceding analysis.

TABLE I.

Principal Dimensions: Source to sample $MN = 20$ cm.
Sample to film $NS = 20$ cm.
Length of sample 2 cm.
Thickness of container 0.025 cm.
Coefficient of absorption in container $\mu_F = 10$ cm.$^{-1}$

Case	$2\theta_k$	SAMPLE Diam.	μ_E	Mass (Relative)	Container
A	60°	0.20	10	50	no
B	60°	0.20	10	50	yes
C	60°	0.20	3	160	no
D	60°	0.20	3	160	yes
E	60°	0.40	5	100	no
F	28°	0.20	10	50	no
G	60°	*0.01	10	1	no
H	60°	0.20	∞	—	no

*Thickness of plate.

A study of the results permits the following conclusions to be drawn:

(*a*) The breadth and the dissymmetry of the band increase as the distance from the centre-line of the film increases, even in the most favorable case, *C*, (Fig. 2). The changes are the more rapid the smaller the value of θ_k (Figs. 7 and 8).

(*b*) The container has little effect in displacing the lines, as appears by comparing cases *A* and *B* (Figs. 3 and 4) or *C* and *D* (Figs. 5 and 6).

(*c*) If the sample is relatively opaque it may be very advantageous to dilute it with amorphous material of negligible

absorption coefficient, the dimensions of the sample being unchanged. The gain due to smaller absorption may far outweigh

FIG. 3.

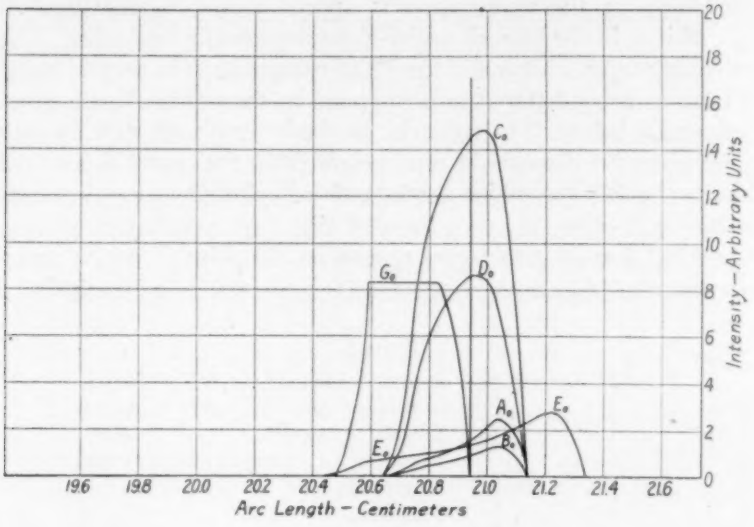
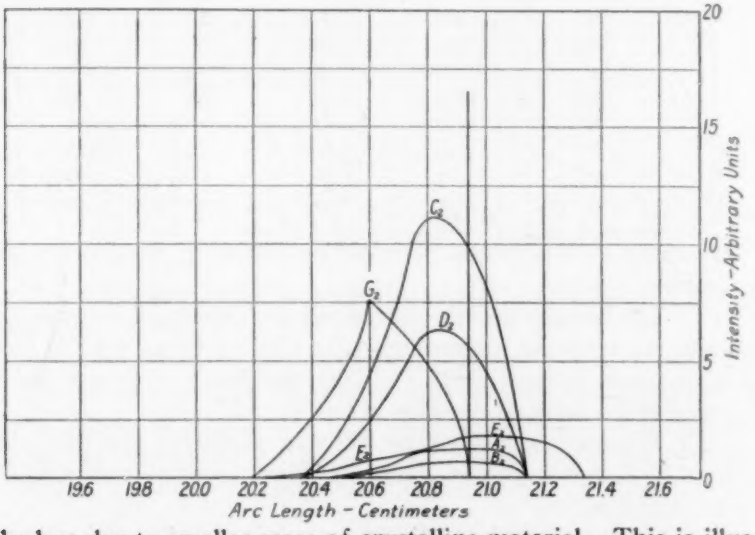


FIG. 4.



the loss due to smaller mass of crystalline material. This is illustrated by cases *A* and *C*, or *B* and *D* (Figs. 3 and 4).

(*d*) It is clear without special proof that the errors in position

of the apparent centres of the bands are nearly proportional to the diameter of the sample. As an example of this compare cases *A*

FIG. 5.

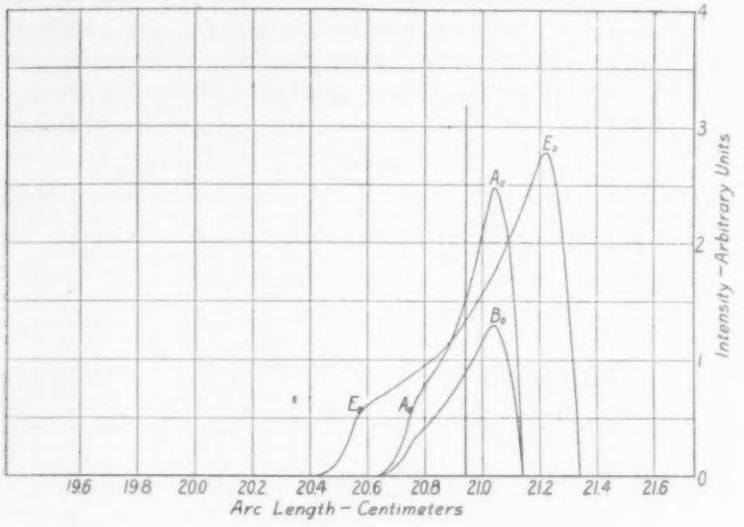
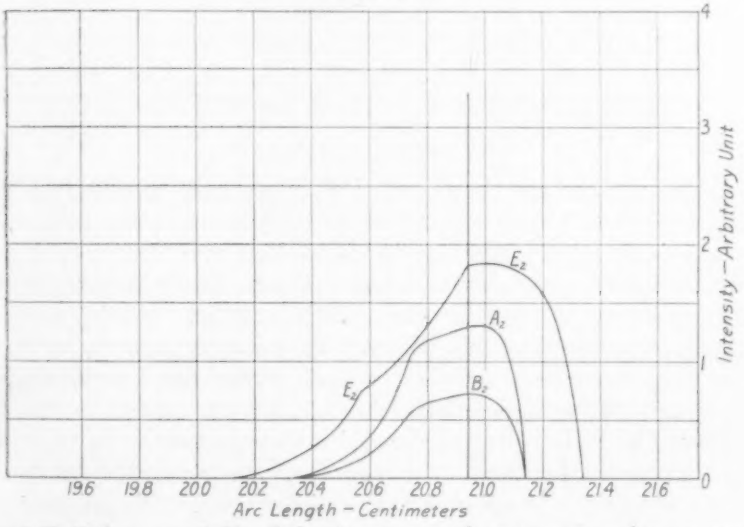


FIG. 6.

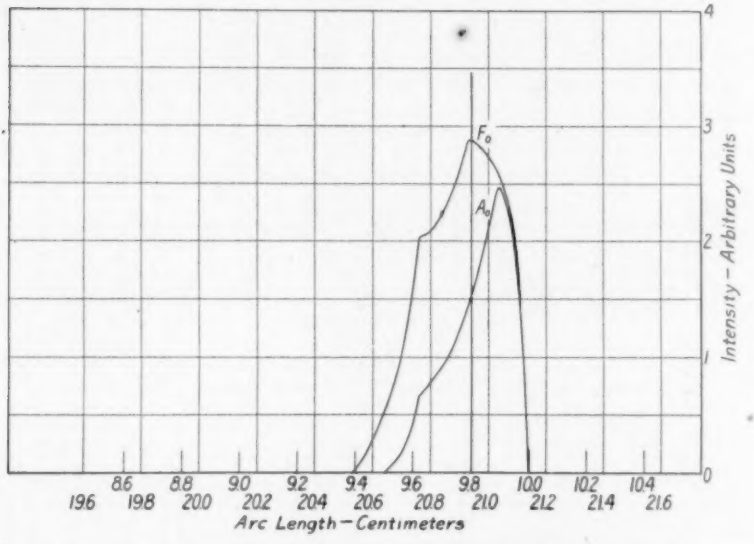


and *E* (Figs. 5 and 6). It is always an advantage to reduce excessive opacity by reducing the diameter of a sample rather than by

diluting it, provided the manipulative difficulties do not become too great.

(*e*) The smaller the value of θ_k the greater is the width of the band and the more dissymmetrical it is. Whether the error in estimating its position is greater or less depends upon other factors. Compare cases *A* and *F* (Figs. 7 and 8). It should be noted that equal percentage accuracy requires greater absolute accuracy the smaller the value of θ_k.

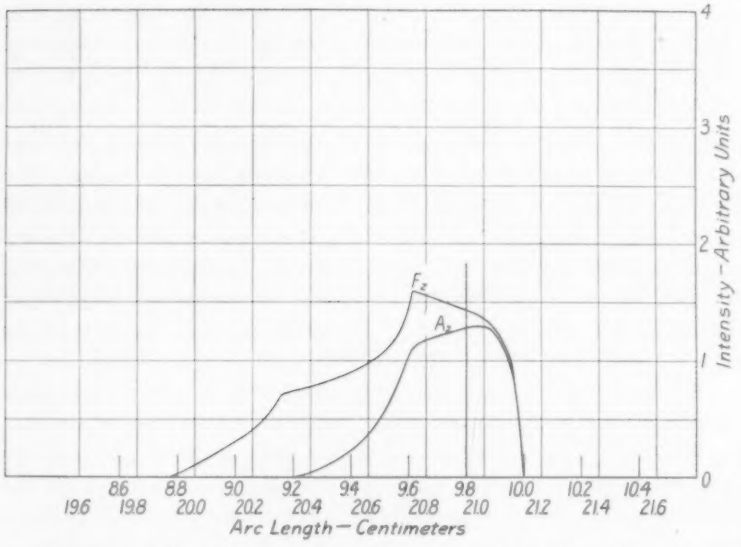
FIG. 7.



Most of the metals of technical importance have such high absorption coefficients that cylindrical samples of suitable diameter for accurate photographs are so small that very long exposures would be necessary. It was found easier to obtain intense photographs by modifying the shape of the sample, replacing a thin circular cylinder by a thin ribbon with one edge along the axis of the film. Calculations similar to those carried out for cylindrical samples give intensities shown in the table and curves as case *G* (Figs. 3 and 4). The point to which measurement must be made in this case is the limit of the band, which is relatively easy to locate even when the photograph is rather faint. The presence of a region of uniform intensity close to this limit makes its location easier than in the previous case. The central spot is also cut more

sharply, permitting additional accuracy in measurement. Neither of these advantages can be gained by shifting the axis of a cylindrical sample and making measurements up to the limits of the bands. Attention is particularly invited to the small mass of material which is necessary for a relatively intense photograph. For the heavier metals particularly, this method of mounting has great advantages. If the grains are too large it is possible to combine this advantage with that obtained by rotating samples of

FIG. 8.



the more usual form, by rocking the plate about its edge through any angle less than $2\theta_m$.

If the opacity of a cylindrical sample is very great indeed the surface elements contribute practically all the intensity photographed and act as does the edge of the thin plate. The observed position of the band requires, however, a correction to be made for the variable position the effective surface elements assume as θ changes. The necessity for this correction has been pointed out by Bijl and Kolkmeijer [4] in their work on the crystalline structures of tin, wherein relatively large rods were used. The limiting case of infinite absorption has been computed as case H (Fig. 2). This case is mentioned by recent investigators as occurring in the case

[4] Bijl, A. J., Kolkmeijer, N. H., *Proc. Amst. Acad.*, **21**, 494-500, 1919.

of magnesium oxide for copper characteristic X-rays [5]. The shape of the curve is excellent for accurate measurement, but the intensity (not to scale in Fig. 2) is vanishingly small.

If the X-rays reaching the photographic film are not monochromatic a complete pattern of bands will be produced by each wave-length present in sufficient intensity. The principal difficulty arises in the actual apparatus, from the fact that both components of the K_α doublet are present in sufficient intensity to affect the film. Since the wave-lengths are 0.712Å and 0.708Å the corresponding parts of the two patterns are 0.10 cm. apart at about 17 cm. from the undeviated spot. When the crystals are sufficiently small resolution of the smooth bands is more difficult and has only occasionally been observed in the best photographs. The extreme edge should always correspond to the lower wave-length, 0.712Å, and this is accordingly to be used in computing the values of d_k when the doublet is not resolved. When large crystals are present in the sample, irregular variations in the intensity within the bands due to a single wave-length are observed, and the larger crystals give lenticular spots [6] clearly resolvable in the case of K_α doublet, and separated by the expected intervals at all distances greater than 6 cm. from the undeviated spot.

The presence of these discrete spots due to the larger grains affords a ready means of observing the early stages in grain growth, and does not materially affect the accuracy with which a value of θ_k can be found until the crystals are so large that they begin to reflect other wave-lengths than those of the K_α doublet and until their number is too few to justify the postulate of random distribution in position and orientation.

CONCLUSION.

Both theory and experiment indicate that, when great accuracy is desirable in the analysis of highly absorbent crystals, a thin plate is preferable to a circular cylinder. If a cylindrical form is unavoidable, the smallest diameter which gives a measurable photograph will be found to be the best.

RESEARCH LABORATORIES OF THE AMERICAN TELEPHONE CO.
AND THE WESTERN ELECTRIC CO., INC.
October 25, 1921.

[5] Gerlach, W., Pauli, O., *ZS. f. Physik.*, **7**, 116-123, Oct. 21, 1921.
[6] Bijl, A. J., Kolkmeijer, N. H., *Proc. Amst. Acad.*, **21**, 407, 1919.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

ANNUAL REPORT OF THE DIRECTOR, BUREAU OF STANDARDS, 1921.[1]

[ABSTRACT.]

In conformity with the general policy of the Government in restricting expenditures wherever possible without serious detriment to the public service, the Bureau of Standards has, during the fiscal year ended June 30, 1921, confined its activities to the more urgent research problems and testing. This has necessarily meant a curtailment in various directions, but it is believed that from the point of view of value received for money expended the year covered by the last annual report of the Director of the Bureau to the Secretary of Commerce has been a notable one.

Close coöperation with the industries and other Government departments, both National and State, has been continued with satisfactory results. The number of tests completed during the year was 67,398 for the Government and 26,638 for the public, a total of 94,036 tests of all sorts. It should be remembered that this work has been carried out with smaller expenditures and a reduced personnel.

During the year the staff of the Bureau has been composed on an average of 342 statutory employees and 508 engaged in special research work authorized by Congress. This is a total of 850 as compared with 981, the average for last year. However, there has been a decided improvement in turn-over of the personnel and the more stable conditions existing during the fiscal year now under consideration have improved the quality of the research work.

Important progress was made during the year in the recomparison of the Bureau's fundamental standards of measurement, and the condition of these is steadily improving.

The Annual Conference on Weights and Measures held on May 23–26 was largely attended; several important questions were considered, including the sale of bread by weight, specifications and tolerances for liquid measuring devices, and the methods of weighing coal.

* Communicated by the Director.

[1] Miscellaneous Publications No. 47.

New specifications for incandescent lamps purchased by the Government were prepared during the year by the Bureau, as the old specifications, written a number of years ago and several times revised, were out of date. A total of 2,750,000 lamps were ordered by the Government during the year, all these orders stipulating that the lamps should conform to the specifications of the Bureau. These specifications are typical of many issued during the year, not only by the Bureau, but by many other organizations with which the Bureau coöperated, covering all classes of materials.

Important work has been done in ways and means for conserving our supply of natural gas, in some of this work the Bureau having the coöperation of the Bureau of Mines.

A thorough investigation of the strength of fire resistance of various types of building construction has been pushed vigorously throughout the year, and the important investigational work on airplane and automobile gasoline engines has been continued.

A spectroscopic method of analyzing gold and other precious metals was successfully developed and turned over to the Treasury Department for their use.

The coöperative research work with the Bureau of Engraving and Printing in the development of a satisfactory electrolytic printing plate has been continued and the process has been in regular use by that Bureau during the year.

Important progress has been made in several metallurgical lines, such as the car-wheel investigation mentioned last year. The work on cement gypsum, and other building materials has also been pushed, but it has been necessary to discontinue a portion of the cement inspection work at the mills.

Optical glass of satisfactory quality has been supplied to the Navy Department, and valuable experience is being gained in the manufacture of this important material.

Research work covering a period of many years will soon have culminated in the preparation of tables on the physical constants of ammonia. This is the most thorough work of the kind ever carried out.

The results of the Bureau's work are made available to the public through its publications, of which 86 were issued during the year. Twenty-four reprints of previous publications and a supplement to the list of publications were also issued. A new series of " Hand-books " has been started and will be made up of weights

and measures manuals, safety codes, etc. Many articles have appeared in scientific and technical journals, written by members of the Bureau's staff, and service has also been rendered through representation on committees, consultation with visitors, and by means of correspondence.

The Technical New Bulletin, describing current investigations, has been issued each month in mimeograph form as heretofore.

INFLUENCE OF PHOSPHORUS UPON THE MICRO-STRUCTURE AND HARDNESS OF LOW-CARBON OPEN HEARTH STEELS.[2]

By Edward C. Groesbeck.

[ABSTRACT.]

SINCE there appears to be scanty information of a systematic nature in the published literature with regard to the influence of varying amounts of phosphorus, especially within the limits usually found in open hearth and Bessemer steel of commercial grades, upon the microstructure and physical properties of low-carbon steel as developed by heat-treatment, this investigation was undertaken with the object of throwing additional light upon the rôle played by phosphorus upon the properties of low-carbon open hearth steels, which are often used in the manufacture of products where severe cold-working is employed during fabrication. Because of the very limited amount of material made available for this investigation, the scope of work was confined to the study of microstructure and hardness, as developed by a series of seven heat-treatments, in specimens cut from 1-inch rounds that had been fabricated from two series of low-carbon steel ingots, one of basic open hearth steel and the other of acid open hearth steel, which Dr. J. S. Unger had prepared several years ago in connection with his investigation into the effect of varying phosphorus-content upon the endurance qualities of low-carbon open hearth steel when severely cold worked. Both series of steels had the general chemical composition: 0.12 per cent. carbon, 0.36 per cent. manganese, 0.022 per cent. silicon, 0.037 per cent. sulphur, and 0.014 per cent. copper, while the phosphorus-content varied within the limits 0.008 to 0.115 per cent.

The series of heat-treatments given the specimens, which were

[2] Technologic Papers, No. 203.

in the shape of a quadrant of ½-inch radius and were ¼-inch thick, consisted of heating the specimens in an electric tube furnace to 900° C., followed by cooling down through the 900° to 600° C. range in the following periods of time: 8 hours, 4 hours, 2 hours, 1 hour, 30 minutes and 10 minutes. In addition, one set of specimens was heated in a lead bath to 900° C. and allowed to cool with the bath down to 500° C. when the specimens were taken out and air-cooled.

A study of the micrographs taken of all the heat-treated specimens at near each corner of the quadrant-shaped specimens showed that there was a marked irregularity in the distribution and size of both the ferrite and pearlite grains in many of the specimens, especially in the acid open steel series, and that there was no definite relation between the occurrence of this irregularity of structure and the phosphorus-content and heat-treatment.

Because of the irregularity in structure, no clearly defined relationship could be established between the phosphorus-content and the grain-size, as determined by the Jeffries method, and also the Shore scleroscope hardness, though a small but definite increase in Brinell hardness could be traced as the phosphorus-content was raised.

This irregularity in structure is evinced in many cases by the presence of large carbonless or pearlite-free areas and abnormally large ferrite grains, was shown by metallographic etching to be due to the non-uniform distribution of the phosphorus, there being a greater concentraton of this element within these areas than in the surrounding metal.

A cellular-like structure formed in conjunction with the microstructure normal to these steels was studied and relationship between this unusual structure and the distribution of the phosphorus was established. This cellular-like structure, as developed by etching with an alcoholic solution of nitric or picric acid, comprised of a light-colored network of cell-wall system with darker-colored meshes, and appeared to be independent of and superposed on the usual ferrite and pearlite system. It was found present in the steels containing at least 0.03 per cent. phosphorus, and was more pronounced as the phosphorus-content increased, which fact was further established by the study of a number of specimens of a medium carbon steel, containing 0.42 per cent. phosphorus, that had been heated to 800° and 900° C. and cooled down through the

800-650° range at various rates. Proof of this relationship between the cellular-like structure and the distribution of phosphorus was given by the etching patterns as developed by etching with Stead's reagent. These etching patterns corresponded exactly in position with and overlapped the cellular-like structure previously developed by picric or nitric acid, and were also more pronounced in the higher phosphorus steels than in the lower phosphorus steels.

CUTTING FLUIDS.[3]

By Eugene C. Bingham.

[ABSTRACT.]

PART I. THEORY.

MACHINISTS have long recognized lard oil as being well-nigh indispensable in certain cutting operations, whereas for the majority of operations in the machine shop much cheaper oils may be used to advantage. The reasons for the superiority of lard oil have not been clearly understood, but they turn out to be closely related to the general theory of lubrication, and with the development of fast-moving machines this theory is of vast economic importance.

One function of a cutting fluid is to cool the work, and for this purpose water with its high specific heat is suited. But since water tends to rust the machines, alkaline substances are added such as soda or soap.

In difficult cutting operations, the chip is apt to "seize" the tool, causing dulling of the tool, roughness of the work, *et cet.*, hence it is inferred that in such cases a good lubricant is required and therefore water is out of place.

The experiments of Tower led many to the erroneous belief that two oils of the same viscosity would have the same lubricating value. Consequently the cheaper mineral oils have been regarded as equivalent in every respect to the fatty oils which they once supplanted. There are certain operations in the machine shop such as the threading of micrometer screws, parting of mild steel, threading and tapping wrought iron, boring gun-barrels in which no mineral oil, regardless of its viscosity, will produce the excellent results obtained with lard or other fixed oils. With lard oil, the

[3] Technologic Papers, No. 204.

surface obtained is smoother, the chip is less serrated and longer, the tool lasts longer, the production is increased, there is less heating, and the machine runs steadier.

It appears that whenever two *clean* surfaces of metal are brought together they tend to seize. Many examples prove that a quite invisible layer of impurity will prevent seizure. The clean metal of the chip moving over the face of the tool under great pressure affords a peculiarly difficult problem in lubrication. Lard oil has a much higher *adhesion* for metal than do the pure mineral oils. It is drawn in between the chip and the tool and forms a strong film which prevents the chip from adhering to the tool and forming a "bead." Other oils containing fatty acids, or groups of atoms with "residual affinities," such as sperm oil, castor oil, rape oil, *et cet.*, have in large measure the advantage of lard oil.

It seems readily possible to improve mineral oils as cutting fluids and as lubricants by adding liquids of high adhesion such as oleic acid, pine oil and fixed oils. Methods are suggested for the measurement of adhesion. While this paper was in the course of preparation, the Deeley friction testing machine and the Lanchester worm gear machine were being developed in Great Britain, which demonstrate the superiority of the fixed oils as lubricants and the advantage of adding fatty oils or their acids to mineral oils to be used as lubricants.

PART II. PRACTICE.

Correspondence with the large machine shops in America with regard to their practice in the use of cutting fluids elicited information worthy of record.

The purposes of cutting fluids are to cool the work, lubricate, lessen wear, insure a good finish with accurate dimensions, wash away chips, and prevent the formation of dust. The materials used may be classified as (a) oils, (b) air, (c) aqueous solutions and water, and (d) emulsions.

Oils may be animal oils, fish oils, vegetable oils, mineral oils or compound oils. The edible animal oils are too expensive to use as a lubricant, hence only the inferior grades are used for this purpose. Fish oils are objectionable unless deodorized, vegetable oils tend to gum, and mineral oils are low in adhesion and are therefore poor lubricants. Compound oils are largely used, containing a large percentage of mineral oil with a smaller percentage of vegetable or animal oil, or both. Air is used merely to remove chips.

Water alone is used to some extent, but on account of the tendency to rust, soda, sodium silicate, sodium resinate or other soap are usually added.

Emulsions have the advantage of cheapness while possessing much better lubricating properties than the aqueous solutions. They are of three types. Mineral oil compounded with neutralized sulfonated oil will form a permanent emulsion when mixed with various proportions of water. Mineral oils are compounded with an alcoholic solution of soap. A third variant is marketed as a paste, it being a thick soap solution and mineral oil. The second type is the most desirable and the third is the least so.

As to the choice of a cutting fluid for a given operation, the character of the operation performed has more to do with the choice of cutting fluid than the character of the metal. For drilling, reaming, milling, planing and sawing emulsions are generally satisfactory. For tapping and threading and parting off compound oils and lard oil are often resorted to. Compound oils are used with automatic screw-cutting machines.

The material cut is also of importance. There is a general consensus of opinion that soft steel and wrought iron are difficult metals on which to get a good surface without lard or sperm oils. They are called "draggy" metals. Cast iron on the other hand, being brittle, does not adhere to the tool and no lubricant is required. Contrariwise, on a hard, brittle steel, lard oil merely produces a "glaze," and turpentine is used with success.

The formulas of cutting oils used by large and successful users are given.

In the search for the true explanation of the remarkable "oiliness" exhibited by lard oil, the surface tension, specific gravity, and specific heat of several oils were studied by A. W. C. Menzies. The fluidity was studied by W. G. Kleinspehn.

TENSILE PROPERTIES OF SOME STRUCTURAL ALLOY STEELS AT HIGH TEMPERATURES.[1]

By. H. J. French.

[ABSTRACT.]

THE report gives results of determination of tensile strength, proportional limits, elongation, reduction of area and strength at

[1] Technologic Papers, No. 205.

fracture throughout the range 20 to 550° C. for four steels containing about 0.38 per cent. carbon, as follows: (a) Plain carbon steel; (b) 3½ per cent. nickel steel; (c) 3 per cent. nickel, 1 per cent. chromium steel, and (d) 1 per cent. chromium, 0.2 per cent. vanadium steel.

Brief reference is made to the type of fractures obtained in testing steels at various temperatures, and particular attention is paid to comparison of the tensile properties of these alloys at 550° C. in the neighborhood of which various parts of converters are subjected to stresses in production of ammonia by the Haber process.

Of the four steels tested in normalized condition it appears that the two alloys containing chromium show greater resistance to weakening by increase in temperature to about 550° C. than either the plain carbon or 3½ per cent. nickel steels, and at this high temperature the chromium-vanadium steel is to be preferred from the standpoint of high tensile strength and limit of proportionality.

The carbon and 3½ per cent. nickel steels behave alike with rise in temperature above that of the room, and at about 550° C. the addition of 3½ per cent. of nickel appears to have little or no effect on the tensile properties of the carbon steel.

Measurements of the Compressibility of Solids. E. MADELUNG and R. FUCHS. (*Ann. d. Phys.*, No. 12, 1921.)—The solid of about 2 c.c. volume was placed in a glass vessel terminating above in a capillary tube. Below a ground-glass joint permitted the introduction of the solid. The remaining volume of the vessel was occupied by mercury which reached up into the fine tube. When pressure was applied externally to the glass vessel and its contents, changes of volume manifested themselves by changes of level in the mercury contained in the tube.

Pressures are expressed in megabars, that is, in millions of dynes per sq. cm. One megabar equals 1.019 kg. per sq. cm. or .987 atmosphere. The pressures employed in the experiments reached to 148.6 megabars. About 60 substances were tested, most of which were minerals. Of all these corundum made synthetically had the smallest coefficient, *viz.*, .38. This means that the application of a pressure of one megabar reduces the volume of this material by .00000038 of its uncompressed volume. For paraffin the corresponding quantity is .00003336, nearly 90 times as great. The need for accurate determinations of compressibility will appear from the following values found by different experimenters for copper—1.25, Regnault; .87, Amagat; 1.61, Voigt; .90, Madelung and Fuchs.

G. F. S.

NOTES FROM THE LABORATORY OF PURE SCIENCE NELA RESEARCH LABORATORIES.*

BRIGHTNESS OF LIGHT SOURCES.

By W. E. Forsythe.

THE brightness of several different light sources has been measured by different methods and previously reported. The values given in the table include some additional data.

The first method used was to measure the brightness with an optical pyrometer having a yellow-green glass as a monochromatic screen. This pyrometer was calibrated, using a black body as standard, so as to give values in candles per square centimetres. The second method was to measure the brightness through a small opening of known size by means of a regular photometer. The third method used was to measure the color temperature and the brightness, and from these values and the known brightnesses of a black body to calculate the brightness.

The results given in the table were all obtained by the use of at least two of these methods wherever it was possible, and those for the different sources—in particular the white mazda and the frosted lamps—are the average of readings obtained on a number of different lamps. Some results previously published are added for purposes of comparison.

Source	Brightness Candles per cm².
Kerosene flame	1.3
4-watt carbon filament	51.0
0.9-watt tungsten filament	227.0
Same lamp frosted	2.5
50-watt white mazda—outside	1.29
50-watt white mazda filament	408.0
2000-watt mazda—outside coil	864.0
2000-watt white mazda—inside coil	2021.0
Same type lamp frosted—outside	105.0

* Communicated by the Director.

RADIATION EQUILIBRIUM IN AN OPAQUE UNIFORMLY HEATED SOLID AND DUANE'S HYPOTHESIS AS TO ITS ORIGIN.

By A. G. Worthing.

WHETHER or not the *natural radiation* from the ultimate sources of radiation in an opaque uniformly heated solid agrees in spectral distribution with the *equilibrium radiation* in their immediate neighborhood depends on the optical constants of the solid. The condition for agreement is constancy in $\frac{k}{\lambda}$, where k (often written nk) is the extinction coefficient and λ the wave-length in vacuo. A considerable tendency toward constancy exists in the measured values of this ratio. Possibly the variations found are real but analogous to those experienced in atomic heats in their relation to Dulong and Petit's law. Whatever the explanation, known difficulties due to surface transition layers seem to justify a tentative assumption of constancy for the purpose of testing theories of the origin of radiation.

Duane's hypothesis,[1] a generalization from X-ray observations, ascribes all radiation to the bombardment of atoms by moving electrons—in the ordinary temperature radiations of incandescent solids the free electrons connected with electric conduction. Starting with three fundamental assumptions, Duane concluded that Planck's distribution law results. Apparently, however, he overlooked the fact that the coefficient A in his statement of Maxwell's law is in general a function of temperature. Fortunately, however, thermionic emission experiments seem to indicate that the concentration of the free electrons in a solid varies in such a fashion, at least for low concentrations and high temperatures, if not in general, as to render the coefficient A constant for this special case.

It is to be inferred from Duane's derivation that the natural radiation from the ultimate sources has the characteristics of black body radiation for free space. This is almost certainly not the case. Black radiation in free space differs from the equilibrium radiation in an opaque solid, and only in case $\frac{k}{\lambda}$ is constant, as stated above, has this equilibrium radiation the same spectral distribution as the natural radiation from the ultimate sources.

[1] *Phys. Rev.*, 7, 143, 1916.

Assuming the constancy of $\frac{k}{\lambda}$ and thus for the natural radiation the same spectral distribution as for equilibrium radiation, it seems necessary to modify Duane's assumption (3) so as to read *the energy radiated per hit is on the average proportional to the fourth power of the speed of the free electron and to the square of the index of refraction for the radiation emitted.* In other words,[2] *the ratio of the energy radiated per impact to the kinetic energy of the impacting electron is proportional on the average to the square of the ratio of the velocity of propagation of the radiation in the solid to that in vacuo.* On the new basis Planck's equation follows without question as to applicability.

In addition to giving certain indications regarding the application of Maxwell's law to free electrons, and pointing out the possibility of a constancy in $\frac{k}{\lambda}$, the discussion shows how Duane's hypothesis, when combined with the assumption of such constancy and with conclusions arrived at independently in other lines of research, gives a satisfying physical concept of processes which may underlie the emission of radiation by its ultimate sources.

NELA RESEARCH LABORATORY OF PURE SCIENCE,
NELA PARK, CLEVELAND, OHIO.

Positive Ray Analysis of Zinc. A. J. DEMPSTER. (*Science*, Nov. 25, 1921.)—From the Ryerson Physical Laboratory comes the announcement that zinc has been found to consist of four isotopes of respective atomic weights—63, 65, 67 and 69. The relative intensities in the same order are 6:7:10:1 From these atomic weights of the isotopes and the proportions in which they occur in ordinary zinc the atomic weight of the latter is calculated to be 65.5.

G. F. S.

On the Theory of Relativity and the Experiment of Sagnac. P. LANGEVIN. (*Comptes Rendus*, Nov. 7, 1921.)—Sagnac caused two rays of light from the same source to interfere after they had traversed a closed circuit in opposite directions. When the entire optical system was set in rotation the interference fringes were shifted by an amount which corresponded to an apparent difference between the times required to traverse the circuit in the two directions. Langevin derives Sagnac's exact expression for this time difference, founding his argument on the Theory of Relativity.

G. F. S.

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[2] As reworded by the writer's colleague, Dr. E. Q. Adams.

The Stability of Atoms. SIR ERNEST RUTHERFORD. (*Proc., Phys. Soc.*, Aug. 15, 1921.)—The mid-Victorian belief in the immutability of the atom even when subjected to "the most drastic physical and chemical agencies available" had, of course, to be discarded at the beginning of the present century when the spontaneous transformation of some of the heavier elements was established.

About the positively charged nucleus of the atom there is a distribution of enough negatively charged electrons to make the entire atom neutral. One or more of these may be detached without causing a lasting change in the atom. "In order to produce a permanent transformation of the atom it is necessary to disintegrate the nucleus." This is very small, having a radius not greater than 6×10^{-12} cm., but its constituent parts are held together by strong forces so that only "a few agencies are available for an attack on its structure." The alpha-particle is a very concentrated source of energy and, in the case of the heavier elements, one such particle out of 10,000 collides with the nucleus. "The case of the lighter elements, however, is much more favorable; for the repulsive forces are so much weaker that we may expect the alpha-particle to enter the nucleus structure without much loss of energy."

When hydrogen or a hydrogen compound is bombarded by a stream of alpha-particles it sometimes occurs that a hydrogen atom is driven ahead with such a velocity that it causes scintillations upon striking a zinc sulphide screen. The maximum range of such H-atoms is 29 cm. under certain conditions. When nitrogen or dry air is bombarded in like manner swiftly moving H-atoms appear, but with a range of 40 cm. This difference of range renders it impossible to ascribe the H-atoms to the presence of traces of hydrogen or of its compounds in the air or nitrogen used. From boron, fluorine, sodium, aluminium and phosphorus such swift H-atoms are ejected by the impact of the alpha-particles. The range of the atoms from aluminium is 80 cm. "It is of special interest to note that H-atoms are only liberated in elements whose mass is given by $4n + 2$ or $4n + 3$ where n is a whole number. No H-atoms are observed from elements like carbon, oxygen and sulphur, whose mass is given by $4n$." In the experiments cited only one alpha-particle in a million breaks up a nucleus.

G. F. S.

Effect of Pressure on the Thermal Conductivity of Metals. P. W. BRIDGMAN. (*Phys. Rev.*, Aug., 1921.)—Pressures up to 12,000 kg. per sq. cm. were used with twelve metals. The conductivity of lead, tin, cadmium, and zinc is increased by the application of pressure, while for iron, copper, nickel, silver, platinum, bismuth, and antimony the opposite effect is produced, iron showing the smallest reduction and bismuth the greatest. For lead and tin pressure produces a greater relative effect on the thermal than upon the electrical conductivity.

G. F. S.

NOTES FROM THE RESEARCH LABORATORY EASTMAN KODAK COMPANY.*

THE PROPAGATION OF LIGHT IN ROTATING SYSTEMS.[1]

By L. Silberstein.

[ABSTRACT.]

A THEORETICAL investigation of the propagation of light in a reference system such as the earth which is uniformly rotating relatively to an inert system. The problem is treated on both the ether theory and on Einstein's relativity theory. Special attention is paid to the theory of a terrestrial optical experiment recently undertaken at the author's suggestion by Professor Michelson, in which the relative phase retardation due to rotation of two beams sent around an optical circuit is to be measured and which may offer a crucial test discriminating between the relativity theory and that of an ether showing partially or totally the spinning motion of the earth. The paper contains also an investigation of the shape of light rays which are shown to become curved, though inappreciably, due to the rotation of the earth.

THE EFFECTS OF SCATTERED X-RAYS IN RADIOGRAPHY.[2]

By R. B. Wilsey.

[ABSTRACT.]

THE effects of scattered X-rays upon radiographic contrast and definition were investigated and improvements given by reducing the intensity of scattered radiation and that produced by the use of intensifying screens or by a reduction of the tube voltage. The loss of contrast due to scattered radiation was found to be much greater for portions of the subject at a distance from the film than for portions close to the film. Reduction of the intensity of scattered radiation by a diaphragm produces the greatest im-

* Communicated by the Director.

[1] Communication No. 123 from the Research Laboratory of the Eastman Kodak Company, and published in *J. Opt. Soc. Amer.*, July, 1921, p. 291.

[2] Communication No. 125 from the Research Laboratory of the Eastman Kodak Company, published in *Amer. J. Roent.*, October, 1921, p. 589.

provement in contrast and definition in those parts of the subject farthest from the film and gives a greater improvement than that offered by reducing the tube voltage from a five-inch spark gap to a three-inch spark gap. Filters placed between the scattering material and the film gave no improvement in contrast. In the detection of faint differences in absorption the removal of scattered radiation gives results much superior to those of any other technique. Definition in the radiography of the thicker parts of the human body is controlled chiefly by the scattered radiation; marked improvement in definition is possible by a reduction of the scattered X-rays. Intensifying screens record the scattered radiation in slightly lesser degree than does the plain X-ray film. In radiographing through a scattered material under conditions that give poor definitions the limitations of intensifying screens in definition are of little importance, but when the definitions can be improved by a removal of scattered radiation the use of intensifying screens does affect unfavorably the definition. The most satisfactory solution of the problem of scattered radiation appears to be the Potter-Bucky diaphragm.

SIZE-FREQUENCY DISTRIBUTION OF PARTICLES OF SILVER HALIDE IN PHOTOGRAPHIC EMULSIONS AND ITS RELATION TO SENSITOMETRIC CHARACTERISTICS. II. METHODS OF DETERMINING SIZE FREQUENCY DISTRIBUTION.[1]

By E. P. Wightman and S. E. Sheppard.

[ABSTRACT.]

THE various methods of determining size-frequency distribution are classified and discussed, and two methods, a quick sedimentation method and a microscopic method are described in detail and experimental data are given for these. The former depends upon the sedimentation of the halide particles in equal portions of their suspensions for increasing lengths of time, and after resuspending the sediments, counting in a hacmacytometer the number of particles in each of them. At the same time, the weights of the various sediments are found by analysis of the supernatent liquids from each, by application of Stokes' law

[1] Communication No. 124 from the Research Laboratory of the Eastman Kodak Company, published in *J. Phys. Chem.*, **25**, 561 (1921).

(Oden's method) or a modification of it the size-frequency can then be determined. The latter, the microscopic method, much longer and more tedious, is that of counting and measuring the projective areas of grains in random samples of emulsion which had been diluted and spread on a microscopic slide. By means of a high-power microscope with camera lucida attachment the particles were drawn and then were further magnified by projection, planimetered and classified. A typical size-frequency curve obtained by the latter method was plotted for a high-speed emulsion.

THE JELLY STRENGTH OF GELATINS AND GLUES.[1]

By S. E. Sheppard, S. S. Sweet and J. W. Scott, Jr.

[ABSTRACT.]

A TORSION dynamometer is described which was designed for the determination of the jelly strength of gelatin and glues under pure shear. The test pieces were cast cylinders. Both the "breaking load" and the percentage twist at break were determined; the product of breaking load X twist, divided by the cross-section of the test piece is taken as jelly strength. No simple relation was found to hold between the concentration of gelatin and jelly strength. Furthermore, the curves relating to these values of different commercial gelatins do not belong to a common family and frequently cut each other. Hence, jelly strength values determined for a single arbitrary concentration give a very arbitrary comparison of the jelly strengths. There appears, consequently, to be no definite relation between the jelly strength at a given concentration and the tensile strength of a dry glue joint.

Effect of the Presence of Small Quantities of Impurities on Sparking Potential in Air. EDGAR MEYER. (*Ann. d. Phys.*, No. 12, 1921.)—In the experiments here considered the sparks passed between flat, parallel electrodes, 4.93 mm. apart. The air pressure was near to 3 mm. of mercury. It was found that as time passed somewhat different potential differences were required to cause the spark to pass and that these divergences failed to disappear when allowance was made for any change of gas pressure that might have taken place. When the sparking potential was about 440 volts the divergences in several instances were more than twenty volts. In vain it was sought to attribute these variations to temperature effects,

[1] Communication No. 96 from the Research Laboratory of the Eastman Kodak Company, published in *J. Soc. Chem. Ind.*, October, 1920, p. 1007.

to mercury vapor and to changes in the surface of the electrodes. Finally water vapor was found to be responsible. Water vapor with a pressure one-hundredth of a mm. of mercury suffices to lower the sparking potential by 80 volts. As the pressure increases from zero the lowering of voltage proceeds until from .01 to .02 mm. of mercury. As the pressure increases beyond this point the sparking potential rapidly rises. Thus is another thread in the tangled skein of the passage of electricity through gases unravelled.

In the same number of the *Annalen*, H. Stuecklein, of the University of Zurich, as well as Professor Meyer, contributes an additional paper on the same subject and confirms the results of the former investigation. When the sparking potential is determined inside of vessels of glass the hygroscopic action of this substance makes it difficult to eliminate from the contained gas the last traces of water vapor. This action is due to the alkali in the glass that is free or loosely bound. Evacuating the vessel with a diffusion pump still leaves enough water vapor behind to influence the sparking potential. The following procedure, however, was satisfactory. The glass parts were treated with boiling water and thus made non-hygroscopic by the removal of the alkali. After the apparatus had been dried out by the passage of air there was still sufficient vapor to affect the sparking potential. The influence of the vapor disappears at last when the process of evacuation is kept up for several days, connection being meanwhile maintained with a P_2O_5 tube. With a less expenditure of time concordant sparking potentials can be obtained by the use of $CaCl_2$.

G. F. S.

Chemical Industry in China is described by WILLIAM H. ADOLPH, of Shantung University (*Jour. Ind. and Eng. Chem.*, 1921, xiii, 1099–1102). Although raw materials are abundant, very little industrial alcohol is produced. A demand exists for plants to manufacture bleach, cement, fertilizers, soap and paints. Pyrite is abundant; and some commercial sulphuric acid is made by the lead chamber process. The Le Blanc process is used for the manufacture of soda. Certain salts, vegetable dyes, and glass have been made by crude processes since ancient times. Large deposits of coal and of ores of iron, tungsten, and antimony exist. China contains but one paper mill with modern equipment. Chrome leather is being produced. The domestic sugar supply is obtained from both the sugar cane and the sugar beet. Dried eggs and vegetable oils are manufactured and exported. The popular demand is for articles "made in China." Intelligent Chinese look to the United States as the source of inspiration and help. The Chinese industrialists desire to equip their plants with machinery and apparatus from the United States; but such plant equipment must be adapted to meet the peculiar demands of the Chinese industry.

J. S. H.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

VOLUME VARIATION OF BOTTLED FOODS.[1]

By H. Runkel and J. C. Munch.

[ABSTRACT.]

DATA on the capacity of bottles and volume of food in bottles indicate that only a small percentage of the bottles of food filled in accordance with good commercial practice should vary in quantity of contents by more than the calculated maximum variations.

Good commercial practice in bottling foods has been considered to be the attainment of conditions in the bottler's state of business in which he (*a*) includes in his orders for bottles the specifications as to capacity when filled to a specific height, (*b*) tests representative samples of every lot of bottles received, rejecting those appreciably under-capacity, (*c*) fills his bottles to a height determined from the results of his tests, and (*d*) has his labels printed with a definite, correct statement of the quantity of contents and applies them unaltered.

The calculated maximum variations in the volume of bottled foods, as given in the following table, have been computed from the weight variation allowed the blowers by the manufacturers, and by the use of the relation between the weight and volume of bottle glass.

Capacity of bottles. Fl. oz.	Calculated maximum variation in volume	
	Individual bottles. Fl. oz.	Average of representative samples. Fl. oz.
½	0.10	0.014
1	.10	.014
2	.19	.027
4	.24	.034
6	.24	.034
8	.29	.041
12	.29	.041
16	.39	.056
24	.39	.056
32	.58	.083
64	1.16	.17
128	1.94	.28

* Communicated by the Chief of the Bureau.

[1] *U. S. Dept. Agr. Bull. 1009*, issued Dec. 16, 1921.

THE OCCURRENCE OF METHYL ANTHRANILATE IN GRAPE JUICE.[1]

By Frederick B. Power and Victor K. Chesnut.

[ABSTRACT.]

INASMUCH as methyl anthranilate in a dilute form possesses a decided grape-like odor, its detection in commercial grape juice appears to have led to the conclusion on the part of some of those engaged in the control of these products that in all cases of its occurrence an artificial flavoring agent had been employed.

The authors have recently had an opportunity of examining a large number of authentic grape juices for the purpose of determining whether methyl anthranilate is a natural constituent of them (*J. Am. Chem. Soc.*, 1921, **43**, 377). It has now been shown that many varieties of the fruit contain this substance in relatively small amounts, and that it is present to the largest extent in juices expressed from grapes of the Concord type. In but few instances could it be regarded as entirely absent. The complete results of the investigation are reserved for a later communication.

THE DISTILLATION OF STUMPWOOD AND LOGGING WASTE OF WESTERN YELLOW PINE.[2]

By M. G. Donk, C. H. Shattuck, and W. D. Marshall.

[ABSTRACT.]

IN coöperation with the University of Idaho, the Bureau of Chemistry undertook an investigation of the destructive distillation of logging and land-clearing waste, particularly of the yellow-pine stumps, in Idaho. The following conclusions were reached:

The only wastes from Western yellow-pine logging suitable for profitable commercial distillation are those resinous stumps which contain at least 50 per cent. or more of resinous heartwood, the resinous heartwood of stumps, dead down wood, and limbs from which the sapwood has rotted away. "Rich" stumps, containing not less than 60 per cent. of very resinous heartwood, probably can be profitably distilled in a commercial plant where the stand of such stumps is dense enough to keep a plant supplied for a number of years.

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[1] Published in *J. Am. Chem. Soc.*, **43**: 1741 (1921).

[2] *U. S. Dept. Agr. Bull. 1003*, issued Dec. 5, 1921.

Single-retort plants, which can be dismantled and moved when necessary, are possibly most suitable for wood distillation in the West, especially in regions remote from the railroad.

The refined turpentine from western yellow-pine stumpwood has higher boiling-point limits and dries more slowly than that from southern yellow pine. Its solvent power is not less than that of wood turpentine made by the same process from longleaf yellow pine. It is suitable for many if not all of the purposes for which wood turpentine can be employed.

The refined pine oil and the crude oils obtained by distilling western yellow pine are valuable for ore recovery by the flotation process.

The crude light and heavy oils have germicidal properties approximately half as great as those of phenol, so that they are useful for shingle stains, wood preservatives, vermin killers and disinfectants.

THE ABSORPTION OF COPPER FROM THE SOIL BY POTATO PLANTS.[4]

By F. C. Cook.

[ABSTRACT.]

INSOLUBLE copper compounds present in a Bordeaux spray containing an excess of lime and in Pickering spray containing no excess of lime and a solution of sulphate of copper were added to the soil near the roots of potato plants in equal strengths and amounts at various intervals during the growing season. Analyses of samples of vines, tubers, and soil gave the following results:

The leaves of the plants grown in the soil receiving the insoluble copper (the sprays) held the largest part of the copper, the roots but little, and the stems an intermediate amount. Only traces of copper were found in the tubers.

Where the soil was treated with the copper sulphate solution the roots were injured and the normal metabolism of the vines was affected. The tubers from these roots were small and the vines stunted. In these plants the roots held more copper than the leaves.

The soluble copper sulphate added directly to the soil caused injury to the plants, but the insoluble copper compounds of the

[4] Published in *J. Agr. Research*, **22**: 281, (1921).

sprays did not. The extra lime of the Bordeaux spray did not reduce the amount of copper absorbed by the plants, as compared with the Pickering spray.

Where the sprays and copper sulphate solution were added to the soil directly, practically the same amounts of copper were recovered from the soil samples. Only minute amounts of copper were found in samples of soil from sprayed potato fields.

"J" Radiation. J. A. CROWTHER. (*Phil. Mag.*, November, 1921.)—Considerable discrepancies have been found between the results obtained by different investigators of the scattering of X-rays that have seemed to indicate the existence of a type of fluorescent radiation having a wave-length much shorter than that of the K series. To this additional kind of radiation the name "J" has been given. Its existence has not, however, been generally accepted and, as the author of the present article says: "Partly because radiation of this type is not indicated by the current theory of the structure of the atom." The attitude of mind hereby indicated is scarcely scientific though it is highly complimentary to the modern geographers of the atom.

Mr. Crowther has investigated the X-rays scattered from paraffin, copper and aluminium and interprets his measurements as explicable by the emission of fluorescent radiations which for substances of low atomic number are weak in comparison with K radiations and which are further different from these in consisting of lines that are rather far apart in the spectrum.

G. F. S.

Separation of Certain Rare Elements by Means of Selenium Oxychloride. HENRY B. MERRILL, of the University of Wisconsin (*Jour. Am. Chem. Soc.*, 1921, xliii, 2378–2387), has used selenium oxychloride for the separation of columbium from tantalum, and of molybdenum from tungsten.

Columbium pentoxide is readily soluble in a boiling mixture of equal volumes of sulphuric acid and selenium oxychloride, while tantalum pentoxide dissolves but slightly in this solvent. When an excess of the pentoxide is boiled for 30 minutes with 50 c.c. of the solvent, the respective solubilities are—columbium pentoxide, 0.35 gram; tantalum pentoxide, 0.005 gram. This difference in the solubility of the two pentoxides is used for their separation from each other in analysis, and also for the preparation of the pure oxides.

When an ignited mixture of the trioxides of molybdenum and tungsten is treated with a boiling mixture of one part by volume of sulphuric acid and five parts of selenium oxychloride, the molybdenum trioxide dissolves while the tungsten trioxide remains insoluble. This separation of the two oxides is quantitative.

J. S. H.

NOTES FROM THE U. S. BUREAU OF MINES.*

TREATMENT OF TUNGSTEN ORES OF BOULDER COUNTY, COLORADO.

By J. P. Bonardi and J. C. Williams.

UNTIL the end of 1918, Boulder County, Colorado, ranked as one of the principal tungsten-producing districts of the world, but in August, 1919, there was practically no production, due to decline in demand, decrease in price, and large importations. The tungsten in this district occurs almost entirely as ferberite, although some hübnerite is found. In the early development of this district, the ores were concentrated in stamp mills designed for gold ores. Present milling practice is by stage crushing and screening, each reduction is followed by concentration by means of devices best adapted to each size. As a rule the first concentration is by jigs, either of the Harz type or Richards pulsating type, the feed varies from 4 to 20 mesh, averaging 10 mesh. Jig tailings are reground by rolls, and after screening may be treated in "fine" jigs of the launder type, yielding 20-mesh product, or may be treated on "coarse" tables. Table tailings are reground and prepared for the slime tables; table middlings may be reground and passed into a middling circuit or held for separate treatment.

Crushing is carried to such an extent that when the tailings are discharged, practically all of the mineral has been liberated. A large proportion of the tails will pass a 100-mesh screen. The ore is first crushed to ¾ to 1 inch with jaw crushers, rolls are used in preparing the mill feed. Ball mills are used for regrinding, and in one mill stamps are used to regrind the mill tailings. Within the past few years stamps have been abandoned for fine crushing because of excessive sliming, and jigs introduced to save the coarse mineral. Canvas tables are installed in all the mills, except one, and their use is said to result in a recovery of about 10 per cent. of the total, although they make a low-grade product which must be tabled.

Extractions vary from 75 to 90 per cent., according to grade

* Communicated by the Director.

and character of ore and grade of concentrate. The concentrates are of two kinds, "crude" and "high" grade. The crude concentrate is utilized in the manufacture of ferro-tungsten and tungstic oxide, the two basic products for producing all compounds containing tungsten. All ferro-tungsten is used as a means of introducing tungsten into ferro-alloys, whereas tungstic oxide is used to produce tungsten powder and chemicals. Tungsten powder is extensively used for introducing tungsten into ferro and other alloys.

The high-grade concentrate—60 per cent. WO_3 or more—is desirable for the manufacture of ferro-tungsten. In making tungsten oxide, by the hydrochloric acid process, the material may range from 20 to 40 per cent. WO_3, but in the soda fusion process, a higher grade, 40 to 50 per cent. is desired, although at one plant ore mining as low as 12 per cent. is used in a fusion process.

Further details are given in Bulletin 187, recently issued by the Bureau of Mines.

METHANE IN CALIFORNIA GOLD MINES.

By Byron O. Pickard and E. D. Gardner.

METHANE is well known to coal miners but it means nothing to the average gold miner, as it is not associated generally with gold-bearing formations. In a recent study of mine air in typical gold mines on the Pacific coast, three out of five California mines showed methane in ignitable quantity. In another California mine not sampled, the superintendent was seriously burned by the ignition of a pocket of gas. One of the three mines mentioned is an old mine that had been abandoned for years but was recently unwatered. Bubbles formed freely on the water, and two men were seriously burned. When sampled, the mine was supposed to be free of methane, but six samples all showed small amounts, 0.04 to 0.07 per cent. In the second mine samples showed 0.01 to 0.21 in different places, and several weeks later two men were seriously burned by igniting gas. The third mine has had small amounts of methane for years, the gas coming from a fractured zone, but care has prevented any serious accidents. Samples of the air showed 0.01 to 0.32 per cent., and near the feeders, 11.6 to 13.5 per cent.

The conclusion is that the methane is given off from certain

carbonaceous rocks associated with the gold-bearing deposits, also that it may be given off from timbers decomposing under water. Steps to insure thorough ventilation and removal of the gas should be taken in any mine where these conditions are present. Further details are given in a recent paper issued by the Bureau.

INSPECTING AND ASSEMBLING FLAME SAFETY LAMPS.

By L. C. Ilsley.

DURING the last few months in the anthracite fields, several explosions resulting in burnings and fatalities, were found to be undoubtedly caused by the use of defective or improperly assembled safety lamps. In nearly every coal-mining country, bonnetted lamps have superseded the unbonnetted types, and while much safer, require more care in assembling because of the greater number of parts.

Further details, with rules for the proper inspection and method of assembling safety lamps, are presented in a recent paper by the Bureau.

A Routine Method for Sulphites. ALBERT E. PARKES describes in the October *Analyst*, a method applicable for the detection of small amount of sulphites in food articles. It is a modification of the combined methods of Schmidt (*Arbeiten aus dem Kaiserlichen Gesundheitsamte*, 21, 226) and of Winton and Bailey (*J. Amer. Chem. Soc.*, 1907, 29, 1499), and in practice has been found to be speedy, sensitive, and efficient, without the disadvantages of the better-known method of reduction by means of zinc to hydrogen sulphide (*U. S. Dept. Agr. Bul. 107*, A.O.A.C.).

Ten grams of the material, such as dried fruit or minced meat or fish, are incorporated with 10 to 20 c.c. of water, by means of a pestle and mortar, and transferred to a small conical flask of about 50 c.c. capacity. In the case of fruit-pulp, glucose-syrup or fruit juice, 10 c.c. may be diluted, when necessary, with 10 to 20 c.c. of water in the flask.

Ten c.c. of dilute sulphuric acid of about 2N-strength and two or three small fragments of marble chips are now introduced into the flask, and the mouth immediately covered with a piece of starch paper (impregnated with a 1 per cent. starch solution), which should be screwed round the neck of the flask, and held in place with a rubber ring. The addition of the marble is to set up a gentle current of carbon dioxide to sweep out the oxygen and the liberated sulphur dioxide. The top of the paper is moistened with one drop of a 1 per cent. solution of iodine.

In the presence of any appreciable quantity of sulphites the blue stain on the starch paper will be immediately discharged by the sulphur dioxide. If traces only be present, it may take a few minutes. The action takes place in the cold; it may be hastened by leaving the flask in a warm place.

If the drop of iodine solution used be of the magnitude of 0.1 c.c. it is obvious that the limit of sensitiveness of the test is the quantity of sulphur dioxide necessary to reduce the iodine and discharge the blue color—namely, 0.00025 gram; and this is the limit usually found when using known amounts of sulphites, showing that practically the whole of the liberated gas is driven out of the flask. This amount, if 10 grams of the material are taken, would represent 0.0025 per cent. of sulphur dioxide.

By using a weaker solution of iodine the test could be made more sensitive, but for a routine qualitative test the strength suggested makes it sufficiently delicate.

Traces of hydrogen sulphide do not seriously interfere with this method, but in practice 1 c.c. of a 5 per cent. solution of copper sulphate is added to the other ingredients when testing meat or fish, and this will retain as much hydrogen sulphide as is likely to be present.

Determination of the Thorium Content of Monazite Sand by Measurement of the Emanation. HOMER H. HELMICK, of the University of Chicago (*Jour. Am. Chem. Soc.*, 1921, xliii, 2003–2014), has devised a method for the determination of the thorium content of monazite sand by measurement of its emanation by means of an electroscope. Two grams of the sand are decomposed by fusion in a platinum crucible with potassium hydrogen fluoride and metaphosphoric acid. The fused mass is permitted to cool, then is dissolved in concentrated orthophosphoric acid. Air is drawn through the resulting solution to remove the emanation, and is then passed through an ionization chamber where the emanation acts upon a charged electroscope. The time required to discharge the electroscope is noted. The determination is repeated, using a standard sample the thorium content of which has been ascertained by gravimetric analysis. A control or blank experiment is also made on the reagents. X, the per cent. of thorium in the unknown, is obtained by solution of the following equation in which A is the per cent. of thorium in the standard, T_s the period of time required for discharge of the electroscope by the standard, T_u the period of time required for discharge of the electroscope by the unknown, and T_b the period of time required for discharge of the electroscope by the blank. $X = A \dfrac{T_s (T_b - T_u)}{T_u (T_b - T_s)}$

J. S. H.

THE FRANKLIN INSTITUTE.

(Proceedings of the Annual Meeting held Wednesday, January 18, 1922.)

HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, January 18, 1922.

DR. WALTON CLARK, *President of the Institute, in the Chair.*

The Board of Managers submitted its report. The report recorded the election to life membership of George Wood Furness, Esquire, and the election to associate membership of Joseph Bernard King, Jr., Esquire; lectures before Sections by Erskine D. Williamson, B.Sc., M.A., Physical Chemist, Geophysical Laboratory, Carnegie Institution, Washington, D. C., on "Change of the Physical Properties of Materials with Pressure," by W. J. Humphreys, C.E., Ph.D., Professor of Meteorological Physics, United States Weather Bureau, Washington, D. C., on "Fogs and Clouds," and by Ralph H. McKee, Ph.D, Professor of Chemical Engineering, Columbia University, New York City, on "Gasoline from Oil Shale"; lecture before the Stated Meeting December 21, 1921, by P. H. Bates, A.B., B.S., Chief, Structural and Miscellaneous Materials Division, Bureau of Standards, Washington, D. C., on "The Application of the Fundamental Knowledge of Portland Cement to its Manufacture and Use"; additions to the library by gift, 60 volumes and 248 pamphlets, by purchase 12 volumes; and contained an extended report by Mr. Charles Day, Chairman of the Bartol Research Foundation Committee of the Institute; and the report of The Franklin Fund and Building Committee, together with the following resolutions:

Resolved, That the Board of Managers of The Franklin Institute recommend to the Institute the election to Honorary Membership of Professor Sir Joseph John Thomson, Master of Trinity College, Cambridge, England, who on the 4th day of January was awarded the Institute's Franklin Medal in recognition of the immeasurable service he has rendered to the world as teacher and leader of thought in that domain of science especially related to a fundamental knowledge of electricity and the constitution of matter.

Resolved, That the Board of Managers of The Franklin Institute recommend to the Institute the election to Honorary Membership of Dr. Ralph Modjeski, of New York City and Philadelphia, who on the 4th day of January was awarded the Institute's Franklin Medal in recognition of his signal achievements as a designer and builder of structures, mainly bridges, many of them epoch marking in the history of the engineering

profession, beautiful as well as useful, involving on the part of the designer, vision, courage and technique of the highest order.

Resolved, That the Board of Managers of The Franklin Institute recommend to the Institute the election to Honorary Membership of Admiral William S. Sims, U. S. N., who commanded the American Naval Forces in European waters during the world war, in recognition of his signal success in the use of scientific and technical methods and means in naval warfare.

On motion duly seconded the report was accepted and the recommendations to elect to Honorary Membership Professor Sir Joseph John Thomson, Dr. Ralph Modjeski and Admiral William S. Sims were unanimously adopted.

The tellers of election, Messers. Hoadly, Picolet and Jennings reported the ballots cast for President, Vice-president, Treasurer and members of the Board of Managers showed that the following gentlemen were elected to the respective offices indicated:

Walton Clark, D.Sc., President (to serve one year).
Henry Howson, Vice-president (to serve three years).
Benjamin Franklin, Treasurer (to serve one year).
Francis T. Chambers, W. C. L. Eglin, Alfred C. Harrison, Nathan Hayward, Charles A. Hexamer, Robert W. Lesley, Marshall S. Morgan, E. H. Sanborn, Managers (to serve three years).
Clarence A. Hall and Haseltine Smith, Managers (to serve two years).

The President read the annual report of the Board of Managers for the fiscal year ending September 30, 1921, commenting upon the reports of the various standing committees of the Institute and of the Board of Managers and detailed at some length the Institute's Parkway building program including the erection, in the near future, of a research laboratory.

The paper of the evening on "The Highway System of the State of Pennsylvania" was presented by the Honorable William D. B. Ainey, LL.D., L.H.D., Chairman of the Public Service Commission of Pennsylvania. Consideration was given to the subject of transportation as a factor in national development and the importance of highways as transportation means. An outline was given of the historical development of highway construction programmes as well as the beginnings and accomplishments of the State Highway System. Brief reference was also made to the past, present and future bearing upon the economic conditions of the State. At the close of his remarks, the speaker called upon Mr. Harold E. Hilts, Assistant Engineer of the Construction Division, State Highway Department, who exhibited a series of lantern photographs of machinery and apparatus used in the construction of roads, as well as a number of views of completed roads in various parts of the state. He described the materials used in road building and the methods of their application. At the close of the meeting a unanimous vote of thanks was extended to Doctor Ainey and Mr. Hilts for their interesting papers.

Adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, January 4, 1922.)

HALL OF THE INSTITUTE,
PHILADELPHIA, January 4, 1922.

MR. C. W. MASLAND, *in the Chair.*

The following report was presented for final action:

No. 2781 and No. 2782 } The Franklin Medal. The Franklin Medal to Dr. Ralph Modjeski of New York and Sir Joseph John Thomson of England.

The following reports were presented for first reading:

No. 2775: Automatic Die Cutting Machine.

No. 2776: Milo-Lite. Dismissed without prejudice.

R. B. OWENS,
Secretary.

SECTIONS.

Section of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, December eighth, at 8 o'clock. Dr. George F. Stradling in the Chair.

The paper of the evening on "The Precise Measurement of Small Time Intervals" was read by Dr. E. A. Eckhardt, Chief of the Sound Section, Bureau of Standards, Washington, District of Columbia. An account was given of the recent developments of the methods of and facilities for measuring small time intervals. The applicability of apparatus and methods to both scientific and industrial purposes was discussed. The applications to the measurement of linear and angular velocities and accelerations, vibration frequencies, etc., were described. The subject was illustrated by lantern slides.

After a brief discussion the thanks of the meeting were extended to Doctor Eckhardt.

Adjourned.

ALFRED RIGLING,
Acting Secretary.

Section of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, December 15, 1921, at 8 o'clock. Dr. H. Jermain M. Creighton in the Chair. The minutes of the previous meeting were read and approved.

Erskine D. Williamson, A.M., B.S., Physical Chemist, Geophysical Laboratory, Carnegie Institution, Washington, D. C., delivered a lecture on "Change of the Physical Properties of Materials with Pressure." The apparatus used to obtain hydrostatic pressures as high as 150,000 pounds per square inch was described. A resumé was given of the changes in certain fundamental electrical and elastic constants produced by the application of high pressures. The lecture was illustrated with lantern slides and a model of the apparatus. The paper was discussed by Doctor Manzies, Mr. Williamson and others. On motion of Doctor Barnes and Mr. Bonine, a vote of thanks was extended to Mr. Williamson. The meeting then adjourned.

JOSEPH S. HEPBURN,
Secretary.

Section of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, January 5, 1922. The meeting was called to order by Mr. Coleman Sellers, Jr., Vice-president of the Institute.

The paper of the evening on "Fogs and Clouds" was presented by W. J. Humphreys, C.E., Ph.D., Professor of Meteorological Physics, United States Weather Bureau, Washington, D. C. The principal types of fogs and clouds were discussed and their mode of formation and significance explained. Interesting facts were given concerning the size of fog and cloud particles; the number of them per given volume; why the air as a whole is never saturated; how clouds float, and how rain is produced; how the altitudes and velocities of clouds are measured; and other such matters concerning these fascinating phenomena of the sky. The subject was illustrated by numerous lantern slides.

After a discussion in which Doctor Stradling, Mr. Wetherill and others participated, the unanimous thanks of the meeting were extended to Doctor Humphreys. Adjourned.

ALFRED RIGLING,
Acting Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, January 11, 1922.)

LIFE MEMBERSHIP.

MR. GEORGE WOOD FURNESS, Jenkintown, Pennsylvania.

ASSOCIATE.

MR. JOSEPH B. KING, JR., The Electric Storage Battery Company, Philadelphia, Pennsylvania.

CHANGES OF ADDRESS.

MR. WALTER ATLEE, 410 N. Hilton Street, Baltimore, Maryland.

MR. F. H. CLARK, Tuscany Apartments, 40th and Stony Run Road, Baltimore, Maryland.

MR. MILTON W. FRANKLIN, General Motors Research Corporation, Dayton, Ohio.

MR. W. L. GARRELS, Manchester, Missouri.

MR. J. H. GRANBERY, 234 West 21st Street, New York City, New York.

DR. CHARLES H. HERTY, Room 343, 1 Madison Avenue, New York City, New York.

DR. WILBUR M. STINE, 3932 Haverford Avenue, Philadelphia, Pennsylvania.

MR. ORIN C. STOUT, 207 Commerce Building, Columbus, Ohio.

MR. E. R. WHITNEY, Commercial Truck Company, Hunting Park and Rising Sun Avenues, Philadelphia, Pennsylvania.

NECROLOGY.

Dr. William Frear, State College, Pennsylvania.

LIBRARY NOTES.

PURCHASES.

CALLENDAR, M. A.,—Properties of Steam and Thermodynamic Theory of Turbines. 1920.

CAMPBELL, NORMAN ROBERT.—Physics, the Elements. 1920.

CARLIER, ANDRÉ H.,—La Photographie Aérienne Pendant la Guerre. 1921.

Federated American Engineering Societies.—Waste in Industry. 1921.

MOORE, BENJAMIN.—Biochemistry. A Study of the Origin, Reactions and Equilibra of Living Matter. 1921.

MOUREU, CHARLES.—La Chimie et la Guerre Science et Avenir. 1920.

PACOTTE, JULIEN.—La Physique Théorique Nouvelle. 1921.

THORPE, SIR EDWARD.—Dictionary of Applied Chemistry, 2 volumes. 1921.

WALKER, MILES.—The Diagnosing of Troubles in Electrical Machines. 1921.

GIFTS.

Abrasive Company, Abrasive Grinding Wheels. Philadelphia, Pennsylvania, 1919. (From the Company.)

Acme Machine Tool Company, Catalogue of Acme Flat Turret Lathes. Cincinnati, Ohio, no date. (From the Company.)

Adams Company, Catalogues 104, 105, 106, 125. Dubuque, Iowa, no date. (From the Company.)

Allegheny Steel Company, Allegheny Steel and Iron Products. Pittsburgh, Pennsylvania, no date. (From the Company.)

Allen-Bradley Company, Bulletin J-1552. Milwaukee, Wisconsin, 1921. (From the Company.)

Allis-Chalmers Manufacturing Company, Bulletin 1118, Polyphase Induction Motors. Milwaukee, Wisconsin, 1921. (From the Company.)

American Hoist and Derrick Company, American Material Handling Machinery for Industrial Plants. New York City, New York, no date. (From the Company.)

American Radiator Company, Booklets of Natural and Artificial Gas Boilers, Round and Square Boilers, Ideal Water Tube Boiler, Sectional Boilers, Peerless Wall Radiators and Engineers' Data on Vento Heaters. Chicago, Illinois, no date. (From the Company.)

American Steam Pump Company, Pumping Machinery. Battle Creek, Michigan, no date. (From the Company.)

Ames Iron Works, Bulletin No. 1000 of Boilers for Every Service. Oswego, New York, 1921. (From the Works.)

Anderson, V. D., Company, Anderson Steam Specialties. Cleveland, Ohio, 1921. (From the Company.)

Autovent Fan and Blower Company, Modern Ventilating Apparatus. Chicago, Illinois, 1921. (From the Company.)

Bailey Meter Company, Bulletins 42 and 60. Cleveland, Ohio, 1921. (From the Company.)

Ball and Roller Bearing Company, Bulletin No. 110. Danbury, Connecticut, no date. (From the Company.)

Bartlett, C. O., and Snow Company, Bulletin 47, Ideas. Cleveland, Ohio, 1921. (From the Company.)

Bethlehem Shipbuilding Corporation, Ltd., Catalogues DA, F-1, O, VI, WA and WB. Bethlehem, Pennsylvania, 1921. (From the Corporation.)

Bignall and Keeler Machine Works, Pipe Machines. Edwardsville, Illinois, no date. (From the Works.)

Bridgeport Safety Emery Wheel Company, Inc., Catalogue C of Grinding Wheels. Bridgeport, Connecticut, no date. (From the Company.)

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Brown Instrument Company, Bulletins of Pyrometers. Philadelphia, Pennsylvania, no date. (From the Company.)

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BOOK NOTICES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 118. The Pressure Distribution over the Horizontal Tail Surfaces of an Airplane, by F. H. Norton. 86 pages, illustrations, quarto. Washington, Government Printing Office, 1921.

The investigation is divided into three parts, of which this is the first. This part includes the complete study of the pressure distribution over two horizontal tail surfaces, one a standard JN4H tail plane, and the other of special construction, which was thicker and with a plan form of higher aspect ratio. The pressures were recorded at flight speeds of 45 miles per hour to 100 miles per hour, and at engine speeds of 600, 900, 1200, and 1400 revolutions per minute, in order to get all of the conditions that would occur in flight. At the same time various modifications were made in the airplane, such as moving the position of the centre of gravity horizontally, and varying the tail plane in angle, section, and plan form. The number of holes on the tail were so numerous (over 200) that the total pressure of the tail under any conditions could be obtained very accurately by integration of the pressure distribution curve. The results are plotted in a large variety of ways in order to bring out as clearly as possible the exact distribution of pressure.

Report No. 119. The Pressure Distribution over the Horizontal Tail Surfaces of an Airplane, II, by F. H. Norton and D. L. Bacon. 40 pages, illustrations, quarto. Washington, Government Printing Office, 1921.

This investigation was undertaken in order to determine whether the results obtained upon model tail surfaces can be used to accurately predict loads

upon the full-sized tail, and also to find the distribution of load when large elevator angles are used, as the loads from such angles cannot be obtained readily in free flight. The method consisted in using a metal horizontal tail surface inside of which small air passages, connecting with a series of holes in the surface, led the pressure off from the tail in rubber tubes. In this way the pressure at each of these holes was measured by a manometer at several angles of attack and several elevator settings. The results show that the model tests give a loading which is equivalent to the loading under similar conditions in the full-sized airplane and that the manner of distribution is quite similar in the two cases when there is no slip stream.

Report No. 124. Aerodynamic Characteristics of Aerofoils, II, Continuation of Report No. 93. 65 pages, illustrations, quarto. Washington, Government Printing Office, 1921.

This collection of data on aerofoils has been made from the published reports of a number of the leading aerodynamic laboratories of this country and Europe. The information which was originally expressed according to the different customs of the several laboratories is here presented in a uniform series of charts and tables suitable for the use of designing engineers and for purposes of general reference.

It is a well-known fact that the results obtained in different laboratories, because of their individual methods of testing, are not strictly comparable even if proper scale corrections for size of model and speed of test are supplied. It is, therefore, unwise to compare too closely the coefficients of two wing sections tested in different laboratories. Tests of different wing sections from the same source, however, may be relied on to give true relative values.

The absolute system of coefficients has been used, since it is thought by the Committee that this system is the one most suited for international use and yet is one for which a desired transformation can be easily made. For this purpose a set of transformation constants is included in this report.

Each aerofoil section is given a reference number, and the test data are presented in the form of curves from which the coefficients can be read with sufficient accuracy for design purposes. The dimensions of the profile of each section are given at various stations along the chord in per cent. of the chord, using as datum the line shown on the curves. The shape of the section is also shown in reasonable accuracy to enable one to more clearly visualize the section under consideration, together with its characteristics.

The name of the laboratory at which the experiments were conducted is given as the authority for the results here presented, with the size of model, wind velocity, and date of test.

THE AMERICAN ANNUAL OF PHOTOGRAPHY FOR 1922. Small 8vo., 296 pages. George Murphy, Inc., New York. Paper, $1.75.

This is the 36th volume of this well-known photographic manual and exhibits the merits that have always been associated with it. It is extensively illustrated, the pictures covering all fields of photography, with, of course, the usual supply of soft focus effects and female nudes. Many articles of practical value are included. The mechanical execution is excellent.

HENRY LEFFMANN.

BLEACHING AND RELATED PROCESSES, as applied to textile fibre and other materials. By J. Merritt Matthews, Ph.D. 8vo., xi-651 pages, bibliography, index and 298 illustrations. The Chemical Catalog Company, New York. $8.00 net.

The author of this book has been long favorably known in the field of textile chemistry and is well qualified to present the subject in a clear and comprehensive form, which he has done. The art of dyeing is a very ancient one and the art of bleaching is necessarily associated with it. In making up the matter, the classification has been according to the materials and not according to the bleaching agents. Textile fibres, of course, occupy the most prominent place in the art, and cotton stands out as a conspicious material. The volume has been written principally to meet the requirements of the textile chemist, approaching it from the practical applications, and not devoting appreciable space to the theoretical principles involved. The phenomena of dyeing and coloring have found extensive studies under the recent developments of physical chemistry, but while theory should be correlated with practice, the problem set by this book is actual methods and not the reasons for them. Numerous illustrations aid in understanding the methods.

The descriptive part begins with a study of wool. A brief historical note is given in this section. The art of bleaching, though of very early origin, was not by direct chemical means, but by the action of light and air; the scientific methods by means of definite chemicals are of much later development. As might be expected the first active chemical agent was chlorine, but although Scheele discovered this in 1774, it was not until 1785 that its bleaching properties were studied with reference to their commercial application. It was not until the dry bleaching powder, prepared first by Tennant early in the nineteenth century, was made commercially available that the full application of the properties of chlorine were secured. This product became, as is well known, one of the most important and conspicious British exports. For many years it was made only by the direct action of chlorine on lime. The processes of bleaching are, in general, oxidation actions, but the direct application of oxygen has not been satisfactory, and it appears that it is the condition of immediate liberation, termed commonly the "nascent state," that is effective.

The text is by no means limited to the mere details of standard bleaching methods. A great deal of information is given as to the character of fibres, and while the textile fibres are necessarily given the largest space, the interesting and highly important question of paper-stock bleaching is given full consideration. Bone, ivory, horn and feathers are also briefly treated. The bulk of the descriptive matter is, of course, devoted to the treatment of the raw materials, including not only decolorization, but the removal of other foreign matters which interfere with either the working up or the dyeing of the fibres. A special chapter is devoted to the removal of dyes, technically known as "stripping." The most difficult colors to remove are alizarine and the mordanted ones. For stripping purposes, with most colors, the substance, termed for want of a more systematic name "sodium hydrosulphite" is extensively used. To the professional chemist, the most interesting and useful chapter is that devoted to the testing of the materials used in the processes described in the

book. This covers more than one hundred pages, the numerous methods being given in careful detail. The complexity of the bleaching and related industries is shown by the many substances used in them. The chapter begins with a consideraton of the requirements of the water supply and the methods of analysis. The important data are color, total solids, suspended matter, hardness, temporary and permanent, and iron. The recommended procedure for total solids is to concentrate 1000 c.c. in porcelain basins to about 50 c.c and finish the evaporation in a porcelain or platinum dish. This is tedious and, with many waters, inaccurate, on account of the partial precipitation of certain salts, portions of which may adhere quite obstinately to the larger dish. Data accurate enough for technical analysis can be obtained by evaporating 100 c.c. in a weighed platinum dish or in lack of that, a quartz dish. The standard methods of determining hardness by soap solution and by titration with acid are described. It will, however, often be found worth while when the supply of a large plant is in question to determine the calcium and magnesium, in samples before and after boiling, by the standard quantitative methods. A note upon a class of mixture, termed in the trade "bleachers' assistants," gives the information that the articles are often mixtures of cheap chemicals, sold as great mysteries at much higher prices than they could be made for by the user. Oils and soaps which are so largely used in certain preliminary and finishing processes are treated very fully. Two salts are noted, which are comparatively recent additions to familiar chemistry, namely sodium hydrosulphite and sodium perborate. The former is a powerful reducing agent, the latter an oxidizing agent analogous to hydrogen peroxide. Both of these salts have received unsatisfactory names. The analogy of the perborates is to the metaphosphates, and it would be more satisfactory if sodium perborate was called "metaborate." Sodium hydrosulphite shares with other oxy-sulphur salts, the confusion that has arisen from the numerous compounds of the group that have been discovered, and for which the standard nomenclature does not automatically provide. There is a disagreement between the formula that Doctor Matthews gives for sodium hydrosulphite and that given in "The Condensed Chemical Dictionary" issued by the same publishing house that issues the work now under review. The dictionary gives $Na_2S_2O_4$, Doctor Matthews gives $NaHSO_2$. There is also another discrepancy. Doctor Matthews gives several commercial forms of the hydrosulphite as "rongalite," while the dictionary applies that trade name to sodium hydrosulphide, a very different salt. The term "hydrosulphite" is unsatisfactory, and really not in accord with the general principles of inorganic nomenclature, but the long series of oxy-sulphur salts seems to defy a systematic naming.

A bibliography and a good index close the volume. The work is a valuable contribution to the literature of one of the most extensive and important industries, and reflects great credit on the author, whose long, faithful and efficient studies have fitted him to deal thoroughly with the subject.

HENRY LEFFMANN.

PUBLICATIONS RECEIVED.

Étude, Geométrique des Transformations Birationnelles et des Courbes Planes, par Henri Malet. 262 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie., 1921. Price 32 francs.

Physique Élémentaire et Théories Modernes, par J. Villey. Première partie molécules et atomes. États d'équilibre et mouvements des la matière. (mécanique, statique des fluids, chaleur, élasticité et acoustique.) 197 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie., 1921. Price 15 francs.

Précis d'Arithmétique, par J. Poirée. 63 pages, 8vo. Paris, Gauthier-Villars et Cie., 1921. Price 7 francs 50.

U. S. Bureau of Mines: Bulletin 187, Treatment of the Tungsten Ores of Boulder County, Colo., by J. P. Bonardi and J. C. Williams. 79 pages, illustrations, plates, diagrams, 8vo. Miners' Safety and Health Almanac for 1922, compiled by R. C. Williams. 53 pages, illustrations, 8vo. Monthly statement of Coal-mine Fatalities in the United States, October, 1921. 8 pages, 8vo. Washington, Government Printing Office, 1921.

National Advisory Committee for Aeronautics: Technical Notes No. 74, Mutual Influence of Wings and Propeller, by L. Prandtl. 6 pages, diagrams, quarto. No. 76, A Mechanical Device for Illustrating Airplane Stability, by F. E. Norton. 5 pages, illustrations, photograph, quarto. No. 77, A Preliminary Investigation of a New Method for Testing Aerofoils in Free Flight, by F. H. Norton. 11 pages, diagrams, photograph, quarto. No. 79, Effect of Aerofoil Aspect Ratio on the Slope of the Lift Curve, by Walter S. Diehl. 4 pages, illustrations, quarto. Washington, Committee 1921-22.

Prices and Cost of Living. From the Monthly Labor Review (November, 1921) of the Bureau of Labor Statistics, United States Department of Labor. 47 pages, 8vo. Washington, Government Printing Office, 1921.

A Contribution to the Determination of the Shape of Molecules. R. GANS. (*Ann. d. Phys.,* No. 10, 1921.)—Results obtained in a study of the light sent off laterally when a beam traverses a gas joined to an interpretation furnished by the Clausius-Mossotti theory lead to definite conclusions regarding the form of the molecules of the gases under examination. Helium molecules have the form of a very elongated prolate ellipsoid, while carbon dioxide, ammonia and carbon disulphide all have two forms which are oblate and prolate ellipsoids.

This work emanates from the Instituto Fisica, La Plata.

G. F. S.

Heat of Formation of Silver Iodide. HUGH S. TAYLOR and WILLIAM T. ANDERSON, JR., of Princeton University (*Jour. Am. Chem. Soc.,* 1921, xliii, 2014–2017), have made calorimetric measurements of the heat produced by the reaction of silver with iodine to form silver iodide. They find that silver iodide has a heat of formation of 15,100 calories. J. S. H.

CURRENT TOPICS.

The Artificial Disintegration of Light Elements. SIR E. RUTHERFORD and J. CHADWICK. (*Phil. Mag.*, November, 1921.)—Within the last three years the former of these authors has shown that when swift alpha-particles pass through air or nitrogen there are produced a few long-range particles capable of detection by the scintillations they cause when they impinge on a zinc sulphide screen. These particles were identified as H atoms from the fact that they were deflected by a magnetic field to the same extent as similarly moving H atoms would be deflected under similar circumstances.

The alpha-rays traveling through hydrogen develop H atoms that cause scintillations on the screen after they have passed through 29 cm. of air. When the rays, on the other hand, move through nitrogen they develop H atoms that cause scintillations on the screen after they have passed through 40 cm. of air. It is clear then that scintillations occurring at ranges greater than 29 cm. cannot be ascribed to the presence of hydrogen or of its compounds. In the present investigation an active deposit of radium C discharged alpha-rays into the substance under examination. Beyond this was the screen on which the scintillations were counted with a microscope. Definite proof was obtained that particles with ranges in excess of 29 cm. were produced from boron, fluorine, sodium, aluminium and phosphorus in addition to nitrogen. No such particles were got from lithium, beryllium, carbon, oxygen, magnesium, silicon and sulphur, nor from these elements of higher atomic weights—chlorine, potassium, titanium, manganese, iron, copper, tin, silver and gold.

When aluminium was bombarded by alpha-particles it was found that the H atoms were projected not only in the direction of the alpha-particles but also in the opposite direction. The range of the atoms in the backward direction was not so great as in the forward course, 67 against 90 cm. of air, but their number, though less, was of the same order of magnitude as in the forward direction. In the case of nitrogen the number of atoms projected backward is very small, if indeed there are any such atoms.

The H atom probably arises from the disintegration of an atomic nucleus caused by the impact of an alpha-particle. Of the elements giving rise to H atoms all have atomic weights either 2 or 3 in excess of some multiple of 4. For example, the atomic weight of sodium is 23, which equals 4 times 5 with the addition of 3. Should the nucleus be composed of several helium nuclei of mass 4 and of 1, 2 or 3 hydrogen nuclei, this structure would agree with what has just been said and also with the fact that no hydrogen atoms have been obtained from those elements, whose atomic weights are

multiples of 4, *i.e.*, carbon and oxygen, and whose nuclei would contain no hydrogen, if the suggested structure be correct.

The authors regard the H atom that is expelled from the nucleus as not incorporated in it but as being a satellite. The production of backward-moving atoms from aluminium may arise thus. The alpha-particle may strike the H atom at such a point in its orbit around the nucleus as to drive it toward the nucleus about which it describes a hyperbolic path, just as a comet approaches the sun, passes it and then moves back toward the regions of space where it formerly was. Only about two alpha-particles in a million are able to liberate swift H atoms. G. F. S.

Reduction of Ferric Salts by Mercury. LE ROY W. MCCAY and WILLIAM T. ANDERSON, JR., of Princeton University (*Jour. Am. Chem. Soc.*, 1921, xliii, 2372–2378), find that, when metallic mercury is shaken with solutions of ferric chloride in either the presence or the absence of free acid, the ferric iron is rapidly and completely reduced to the ferrous state. The same phenomenon occurs with solutions of ferric sulphate, if a small amount of either free hydrochloric acid or an alkali chloride be present. Titanic acid is not reduced under these conditions. This procedure may be used to reduce ferric salts prior to the volumetric determination of iron by titration with either potassium permanganate or potassium dichromate. J. S. H.

Subsalts of Bismuth. HENRY GEORGE DENHAM, of the University of Queensland (*Jour. Am. Chem. Soc.*, 1921, xliii, 2367–2371), has prepared a suboxide of bismuth BiO and certain compounds of bismuth in which that metal likewise is bivalent. The suboxide is obtained by heating basic bismuthic oxalate under reduced pressure for a period of six to eight hours at a temperature of 250° to 260° C. When the suboxide is treated with methyl iodide at a temperature of 260° to 262° C., several products are formed: (1) Bismuth suboxyiodide, $2BiI_2.3BiO$, a non-volatile, brick-red solid; (2) bismuth subiodide, BiI_2, a red, volatile solid which crystallizes in the orthorhombic system, and (3) a pale yellow distillate which apparently contains bismuth dimethyl, $Bi(CH_3)_2$; this compound readily oxidizes to a strongly reducing substance, possibly dimethoxy bismuth, $Bi(OCH_3)_2$.

J. S. H.

Notes on the Method of Dimensions. E. BUCKINGHAM, Bureau of Standards. (*Phil. Mag.*, November, 1921.)—In speaking of this method of deriving the relations which hold between the physical properties concerned in any phenomenon the remark is made "Lord Rayleigh's numerous applications are sometimes so concisely described that the results seem rather like magic. But while a closer study of his solutions can only increase our admiration, it will certainly lead the average reader to wish for a less intuitive

and more systematic procedure for obtaining the same sort of result. Such a routine procedure is provided by the requirement of dimensional homogeneity as a general algebraic theorem, which was first established by Riabouchinski." Doctor Buckingham shows how to attack a problem by the dimensional method, for example—"Let it be required to find how the resistance R of still air to the motion of a smooth sphere depends on the speed S." In two other problems he shows how to detect the insufficiency of the original statement of the problem and after detection how to remedy the defect. And let it not be thought that this mode of treatment lends itself to recondite problems alone, for it is brought to bear on the heating of a bearing which supports a journal. The various difficulties which may be encountered are stated and appropriate procedures are given. There is so much ripened good sense in this article that it cannot be too highly commended to those having any interest in the subject, and it can scarcely fail to interest any reader equipped with the modicum of physics and mathematics necessary for an understanding.

"Dimensional equations are conventional short-hand descriptions of general relations which subsist among physical quantities of different kinds, and the distinguishing peculiarity of dimensional reasoning is that it uses the known facts of physics only in this general form. . . . As regards accuracy, it may be remarked that the results of dimensional reasoning are subject to the same limitations as those of any other theory. Theory always operates on an ideally simplified picture of reality because real phenomena are unmanageably complicated. The results obtained are not exactly true for any real phenomenon, though they may be for an ideal one; and the approximation with which a theoretical equation, however obtained, represents the actual facts, always depends on the approximation in essentials between the ideal picture and its real prototype." "What is needed for the successful use of dimensional reasoning is neither algebra nor metaphysics, but only practice and a very modest portion of that physical common sense which the late Lord Rayleigh exhibited in so eminent a degree."

G. F. S.

Diffusion of Solid Lead into Itself. J. GRÓH and G. v. HEVESY. (*Ann. d. Phys.*, No. 11, 1921.)—These Budapest investigators last year published an interesting application of isotopes. Just as others had used colors or electrical potentials or indices of refraction to reveal the progress of diffusion, so they, desiring to study the diffusion of liquid lead into itself, came upon the happy thought of making one part of the lead radio-active by the addition of thorium B, an isotope of lead. As this portion of the lead diffused into the other part consisting of ordinary metal its advance manifested itself by the appearance of radio-activity. They now attack the similar problem in the case of lead in the solid state.

The former indicator, thorium B, must be ruled out because in

10.6 hours one-half of it is transformed and the length of the experiments with solid lead will last months rather than hours. As active material to serve as an indicator lead from Joachimsthal (that locality so often mentioned in the early literature of radio-activity and even more deserving of fame in America for having made the word "dollar" possible) was selected. It is a mixture of ordinary lead, uranium lead and radium D, of which the last alone is radio-active. A cylinder of lead and a similar one of lead with radio-active content were melted together at the surface of contact. For more than a year the compound cylinder was kept at a temperature of 280° C., 46° below the melting point of the metal. At the end of this period it was impossible to detect any diffusion of the active lead into the other end of the cylinder. Twenty-five years ago Roberts-Austen studied the diffusion of solid gold into lead, and, strange to say, obtained a coefficient of diffusion about 300 times as large as the upper limit of that quantity for lead into lead, as fixed by the negative result in view of the conditions of the experiment. Now why should gold molecules be able to work their way into lead at a faster rate than lead molecules themselves can penetrate? The suggestion is made that when gold goes into lead it breaks up to some extent the crystalline structure, thus facilitating the entrance of subsequent gold molecules, while a lead molecule leaves this framework unimpaired.

G. F. S.

A Study of the Ultra-violet End of the Solar Spectrum. CH. FABRY and H. BUISSON. (*Jour. de Phys. et le Radium*, July, 1921.)—The ultra-violet end of the solar spectrum rapidly diminishes in intensity from the wave-length 3000 angstrom units downward and no radiation at all is observable beyond 2900 units. As the sun approaches the horizon and its light must pass through a thicker stratum of atmosphere, the smallest wave-length that can be detected moves progressively toward the longer wave-lengths. This indicates that absorption by the earth's atmosphere plays a preponderating rôle in the reduction of intensity of the ultra-violet radiation. Ozone has been advanced as the substance capable of producing such absorption. It is definitely known that this gas is responsible for certain absorption bands in the region of 3300 units which occur in the light of the sun and of the stars. In the entire absence of quantitative measurements of intensity in the ultra-violet the attribution of the absorption effect to ozone has not rested on a very secure basis. The French investigators began by studying the absorption of radiation by ozone. The results were published in 1913. Then came the war during which the scientists of France, turning from academic pursuits, gave themselves to their country in order to help in saving it from the invaders. Now they have resumed their normal work and have studied the absorption of the ultra-violet by the earth's atmosphere. A comparison of this with the previous results obtained for ozone—a comparison made wave-length by wave-length—shows that a layer of ozone about

three millimetres deep at atmospheric pressure would be adequate to account, both quantitatively and qualitatively, for the observed absorption in the earth's atmosphere. A determination of the thickness of this layer from day to day shows that it varies through a range of 17 per cent. Where is this ozone located? Not near the earth, because Strutt has measured the absorption of a certain ray by 6½ km. of air near the earth and found it much less than would have been the case were the above stated quantity of ozone uniformly distributed through the atmosphere. It must then be in the higher regions of the atmosphere that the absorbing ozone exists. It may well be that there the radiation from the sun of wave-length shorter than 2000 units transforms part of the oxygen into ozone. Such radiation from a terrestrial source certainly does this. It is suggested that the variation of the solar constant, proved to exist by Abbot, may account for the changes in the quantity of ozone in the atmosphere.

From a knowledge of the absorption coefficient of the atmosphere for each wave-length the investigators are able to calculate the intensity of the ray outside of the earth's atmosphere. No systematic change of intensity depending on wave-length manifests itself. This indicates that it is not absorption by the sun's atmosphere that sets a limit to the spectrum—a conclusion confirmed by a comparison of the light from the centre of the sun with that from the edge. The effectiveness of the earth's own atmosphere in absorbing light is such that only a millionth of the energy possessed by a short wave-length at the upper confines of the atmosphere finally reaches the earth.

G. F. S.

An Interferometer for Testing Camera Lenses. F. TWYMAN. (*Phil. Mag.*, November, 1921.)—The instrument in its general outlines is based on the Michelson interferometer. "The apparatus measures the degree to which the wave-front, impressed by the lens on light from a distant point source, differs from a spherical wave-front. The interference fringes form a contour map of the wave-front with reference to a sphere." "If the observer be given for test a photographic lens he can within one hour hand the lens back with a record and photographic plate affording the following information:

"a. Focal length of the lens correct to 0.001 inch for the green and violet rays.

"b. Complete aberrations (including distortion, and the chromatic variations of aberration) for axial pencils and for five obliquities."

G. F. S.

The November, 1921, issue of the *Philosophical Magazine* is interesting from the point of view of the geographical distribution of the authors of the contributions. In all twenty-six papers are

printed. Prof. Nihal Karan Sethi, of the Benares Hindu University, and, jointly, C. V. Raman and K. Seshagiri Rao, and, again jointly, C. V. Raman and Goverdhan Lal Datta, of the University of Calcutta, present papers in the field of optics, while from A. L. Narayan, Maharajah's College, Vizianagaram, Madras, comes a paper "On Sounds of Splashes." There is at least one paper from Wales, and one from Oxford, while Cambridge contributes a larger number. London and Manchester are represented. R. W. Wood, of Johns Hopkins, L. T. More, University of Cincinnati, E. P. Adams, of Princeton, and E. Buckingham, Bureau of Standards, form the contingent from the United States.

G. F. S.

Researches on Vagabond Currents. J. CHAPPIUS and HUBERT-DESPREZ. (*Comptes Rendus*, Nov. 14, 1921.)—The currents referred to are such as wander from an electric generator through pipes in the ground and through the earth itself back to the generator. In a city there is likely to be a group of several such currents superimposed and flowing through the same conductors. A method of determining the sources is much needed.

When a vagabond current is made to actuate a telephone receiver a sort of frying sound is heard to which components are contributed by sudden variations in trolley currents, by changes in the speed of dynamos and also by those undulations in the current developed by direct-current dynamos which are due to the impossibility of maintaining the current unchanged from the instant a brush passes over to one segment of the commutator until it makes the next similar change. The experimenters developed a resonance arrangement by which the sound due to the undulations could be isolated from the sound complex and its frequency measured. As the latter depends on the number of revolutions per second made by the armature and on the number of segments on the armature there is something individual and characteristic about it. There might, however, be several dynamos emitting undulations of the same period. How shall the very "fons et origo malorum" be selected from several possible contributing dynamos? This was accomplished by connecting a three-electrode vacuum tube to the dynamo circuit in such manner that vibrations caused by the voice or by whistling could be superimposed on the current from the generator. If a stray current was found to give in the telephone receiver these added sounds, its source was at once known beyond question.

G. F. S.

Sea Casualties and Loss of Life.—A paper on this subject was presented lately before the Northeast Coast Institution of Engineers and Shipbuilders (Newcastle-on-Tyne) by Sir W. S. Abell. The question of safety at sea has been a matter of interest from the earliest times, but it is, perhaps, true that property was at first more

considered than persons. Modern practise is better. The data are collected by the study of returns from the years 1890 to 1913. It is, of course, impossible to apply the figures from the war years to a generalization. Numerous diagrams are given to show the summation of the data and the bearing of different causes of the disaster on the figures. Two disasters attended with great loss of life under exceptional conditions are included, but otherwise the several incidents were of the usual type. The two great disasters were the torpedoing of the transport *Kow Shing* in 1894 by which nearly 1200 were lost, and the sinking of the *Titanic* in 1912, whereby 825 passengers and 673 of the crew were drowned. These two incidents do not materially affect the percentage of loss of the crew, but do increase a good deal the percentage of passenger loss. The following classification on the basis of 100 is given as the approximate results of the study of the several circumstances that may cause loss:

Weather conditions	37
Errors by personnel	25
Defects of ship or machinery	17
Fire	7
Miscellaneous	15

The loss of life in stranded vessels is much greater than when the ship founders on the deep sea.

Assuming that 1,000,000 are carried per year, it seems that only by absolute perfection in the ship itself will it be possible to bring the loss of life down to seventy per year. It is pointed out that the risks of land travel are greater than those by sea. Though the numbers of deaths from most methods of land travel have diminished in recent years, the enormous increase in automobile casualties has maintained the loss of life at the 1906 figure. H. L.

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